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GODDARD SPACE FLIGHT CENTER

GREENBELT, MD.

SYNCHRONOUS OPERATIONAL METEOROLOGICAL SATELLITE FEASIBILITY STUDY

June 1966

Systems Division

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

CONTENTS

I. INTRODUCTION

Present indications are that meteorological satellite technology is on the threshold of an advance comparable to the first Tiros and Nimbus flights. This advance will be accomplished in early 1967 by means of a spin scan camera to be flown on the first launch of the Applications Technology Satellite (ATS-B). This camera will permit continuous daytime observation of cloud cover to be achieved for the first time. It is expected that the continuous monitoring of cloud motions can be accomplished from synchronous altitude with a picture resolution varying from 2.7 to 7 nautical miles.

The purpose of this study is to indicate a means by which this new technique can be exploited on a quick reaction basis by means of the use of existing synchronous satellite technology. The study reported herein will lead to the definitization of a Technological and Management Plan which will permit the launch of a prototype meteorological satellite approximately 18 months after program approval.

The study indicates the preferred method of carrying out the above objective. The method chosen leans heavily on the use of existing spacecraft technology as evidenced by the HS-303A (Intelsat II) as a means of minimizing development costs. It should be understood that this is not the only means by which this proposed program can be implemented, but rather one of several possible approaches.

The tradeoffs mentioned in the study have been evaluated and the most reasonable decisions reached, based on the information available at the time of the study. The conclusions reached in evaluating and deciding on the several tradeoffs have led to a system definition which is feasible. It is the preferred system, not the only one which is feasible, but one sufficiently defined to give high confidence that it can be achieved within the constraints of the program.

II. OBJECTIVES AND CONSTRAINTS

A. Objectives

The SOMS has two objectives: 1) to provide a synchronous satellite which can obtain daytime cloud cover pictures of the portion of the earth within its field of view on a continuing basis; 2) provide a communication and data dissemination capability for meteorological purposes.

The cloud cover pictures are to be obtained by means of a spin scan camera. The camera will require a period of 20 minutes of scan time. A new picture can be initiated every 22 minutes. Thus, it is possible to examine cloud cover approximately three times every hour. From synchronous altitude, the cameras will have a 16^{o} field of view, covering latitudes from 57.4^{o} N to 57.4^{o} S and a total longitude of approximately 115^{o} at the equator. Picture resolution will vary from 2.7 nautical miles at the sub-satellite point to approximately 7.0 nautical miles at a zenith angle of 65.4^{o}.

The communication and data dissemination objective is to provide a means for disseminating the prime pictures directly to all regional centers. The communications link also provides a means for two-way transmission of information between regional centers as well as the means by which processed meteorological data can be transmitted to a number of small ground stations in the field of view of the spacecraft.

B. Constraints

In planning the SOMS system, cost and schedule considerations were prime factors imposed on the design study. For this reason, spacecraft redesign was kept to a minimum and emphasis was placed on providing low cost ground stations for the world, regional and forecast centers. The other basic constraint is the quick-reaction schedule requirement, which calls for a launch 18 months after program go-ahead.

As a result of the above basic constraints, it was necessary to utilize state-of-the-art hardware wherever possible, with no deviations from the philosophy being permitted unless a clear technical advantage was thereby obtained. It was, therefore, made a requirement that the existing technology developed in previous synchronous satellite launches be utilized wherever possible to carry out this mission. A final mandatory requirement was that the Delta be used as the launch vehicle for this program.

In choosing the operating frequencies for the program, it was anticipated that there would be an allocation problem if either standard R & D command-telemetry or commercial communications frequencies were selected. Therefore, the choice of frequencies was limited to those which presently appear available for use as operational meteorological frequencies. Limitation of possible frequencies to the above ruled out compatibility with APT (automatic picture transmission) ground stations. Since APT compatibility was not a requirement for the program, this limitation was accepted for the present study.

The requirement that proven spin scanners be used for this program limits the SOMS to obtaining daytime pictures only. Thus, there are no plans to obtain any night-time earth images.

A final constraint placed on the system capability is that the spacecraft batteries are not of sufficient capacity to permit camera or communications operations when the spacecraft is in eclipse. Since the eclipse season for a synchronous satellite only occurs twice a year (reaching a maximum of approximately 70 minutes a day during a 40 day period for each eclipse season), it was believed that this loss of operations through the eclipse period was not serious.

III. SYSTEM CONFIGURATION

The solution to the problem of providing continuous cloud cover pictures from synchronous orbit will be demonstrated if the ATS-B launch is successful and the camera operates as predicted. However, the implementation of this camera system in an operational synchronous meteorological satellite requires that certain ground rules be established and the necessary system tradeoffs made. The ground rules are generally covered by the objectives and constraints outlined previously; the decisions made relative to system tradeoffs and added to these ground rules led to the final recommended system contained in this study.

Broken into its simplest elements, the SOMS could utilize an HS-303A spacecraft with redundant spin scan cameras added. The basic technical elements which must be added to the HS-303A spacecraft are the cameras and a meteorological data transmission system. The camera addition must be done in any event; the communications system could be accepted with no improvements. However, this seriously limits the meteorological communications compatibility. In order to provide multiple access, an improved communications system utilizing Time Division Multiplex (TDM) is recommended.

A. Spin Scan Imaging

Two spin scanning devices were added to the basic HS-303A spacecraft structure. The intent, similar to ATS-B, is that the east-west scan be accomplished by the nominal satellite spin of 100 revolutions per minute and that the north-south scan be accomplished by a vertical indexing technique - i.e., the optical axis of the telescope is tilted from $+8.0^{o}$ to -8.0^{o} in 2000 discrete steps during the period required to take one picture. The total scan time for one picture is 20 minutes, and a picture can be taken approximately every 22 minutes (including 2 minutes to reposition the optical system). The indexing arrangement allows earth coverage from 57.4^{o} North latitude to 57.4^{o} South latitude and approximately the same in the east-west direction. The completed picture comprises a 2000 line raster. Resolution from synchronous altitude is calculated to be 2.71 nautical miles at the spacecraft subsatellite point and 6.95 nautical miles at a zenith angle of 65.4^{o}. It is not anticipated that useful meteorological data can be obtained at greater zenith angles than 65.4^{o}.

The nature of the spin scan method of imaging leads to the fact that actual scanning is done only 5% of the time, since the camera is pointed to the earth for only that portion of the total spin time during each revolution.

As described previously, the scanner generates a line of video information each time its optical axis sweeps past the earth due to the rotation of the spacecraft. However, in order to utilize the video data at a ground station and construct a picture, a reference signal must be provided so that the consecutive lines of video can be properly oriented with respect to each other. Time displacement between consecutive lines will result in geometrical distortion of the reproduced image, unless kept within tolerable boundary limits (i.e., less than one-half a resolution element).

One of the basic problems is thus to precisely determine the satellite spin speed and then time the initiation of each horizontal scan line. Sun pulses are used for the timing reference, and are generated from a solar sensor provided within the satellite. However, a characteristic phase jitter is associated with these sun pulses. Unfortunately, precise determination of spin speed cannot be accomplished easily due to the noisy nature of this sun sensor signal. Sun signal noise gives rise to both an inaccurate position reference and an incorrect spin speed indication if used on a rotation-to-rotation basis. The sun sensor signal must therefore be considered over a long averaging period before results of sufficient accuracy can be achieved. This averaging process is accomplished in a phase locked loop system.

When synchronization is achieved, the synchronizer generates a constant number of clock pulses for any satellite spin rate and each clock pulse is used to increment the recording beam in the ground station photofax recorder, one resolution element at a time. The synchronization system also includes a control which initially provides the required time delay between the sun pulse and line sync pulse, since this interval is a function of the time of day at which the camera is turned on. This initial time delay is manually set into the system. A time-of-day correction clock then continually adjusts for the constant and precisely defined shift in angle between the local vertical and the earth-sun line once the initial time delay has been established.

The line sync pulses, resolution element clock pulses, and frame start data are then fed to a photofax recorder for production of a pictorial image. In addition, the video and sun pulse signals are tape recorded so that the data are available for future processing.

B. Communications and Data Transmission

It is necessary to transmit the spin scan camera picture information plus the communications signals being relayed by the spacecraft to the ground stations.

The proposed system provides for one 100 WPM teletype channel and 13 simplex, 3.85 kHz data channels which can be used for the transmission of any type of data normally transmitted over a telephone line. The 13 data channels can be used simultaneously by 13 transmitting stations, each station using one channel. A larger number of stations can be accommodated if they can tolerate waiting for an open channel in the event all channels are in use at the time. If fewer than 13 stations use the system, then more than one channel can be assigned to some stations when traffic density requires it. Any number of stations can operate in a "receive only" mode and will be able to synchronize with the transmission to allow the extraction of any channel(s). The transmission is in "near real time" with an additional delay introduced that should not be apparent to the user even in the case of two-way telephone conversation. In addition to the 13 data channels, a 100 word per minute teletype channel will be provided for broadcast to small economical stations equipped to receive this channel only. Of course, all other stations will also be able to receive this teletype channel in addition to the 13 data channels. It is also feasible to supply several teletype channels along with each of the data channels. It can be used simultaneously for both data and teletype but can only be received by those stations equipped to receive the data channels. The transmission of the spin scan camera output to the ground station will be in real time so that only approximately 5% of the time will be used in transmitting these data. It is necessary on the ground, however, that this transmission be accurately synchronized with spacecraft rotation so that adjacent lines of the image register properly. To accomplish this synchronization, the output of the sun sensor is transmitted down to the receiving station during the 95% of the time when no scanner signal is present. The receiving station develops the required sync signals from the sun sensor signals.

After receipt of a picture at the master station, it can be sent via facsimile to a small station having fax facilities.

The spin scan camera signal and the relayed data signals are limited separately and amplified in the same travelling wave tubes and transmitted to the ground stations. Figure 1 shows a simplified block diagram of the communications transponder. The communications signals and the command signals are received on a common antenna, converted to I.F. in two separate mixers and amplified in two separate I.F. amplifiers. The command signals are decoded and fed to the logic equipment to perform the required commands. The communications signals are amplified, limited and filtered after which they are added to the beacon, scanner, and sun pulse signals. The resultant of the combined signals is up-converted, amplified in the travelling wave tubes and transmitted to the ground stations. Figure 2 shows the spectrum on the up and down links.

The Communications System

A TDM (time division multiplex) system has been chosen for communication. It allows a number (up to 13 in the proposed system) of ground stations to send their signals through the spacecraft transponder at one time without interference with each other and without imposing difficult power control requirements on the transmitting stations. Any signals that can be accommodated on a normal 3.85 kHz telephone line can be sent over any one of the 13 data channels provided. Any properly equipped receiving station can receive all channels and demultiplex them to extract the desired information in one or more channels.

In addition to the thirteen data channels, a narrow band 100 WPM teletype channel is provided. This can be received by a small inexpensive ground station as well as by all other stations in the system. It has been assumed in this study that the standard seven unit Baudot teletype code will be used. This code consists of a start, a five unit character code, and a stop pulse. At a printing speed of 100 WPM it requires 100 milliseconds to send one character which consists of seven units. To simplify the synchronization of the teleprinters at the small receiving station, a frame rate of 10 per second (100 millisecond period) has been chosen. At the transmitting station the teletype signal to be transmitted is fed to a special digital data modem. This modem separates the five unit character code from the start and stop pulses. The five unit code is then formatted for transmission in the assigned time slot within the frame.

At the small receiving station the five unit character code is received and fed into a different special digital data modem wherein start and stop pulses are inserted and the resulting signal is put into the standard 100 WPM Baudot format.

Figure 3 shows the make-up of a typical frame. The frame rate of 10 per second has been chosen to simplify the synchronization for the small receiving station. The input analog data channel is sampled at a 7.7 kHz rate yielding a baseband bandwidth of 3.85 kHz. The sample is encoded into a 7 bit code. In the period of one frame, therefore, the analog data signal will be sampled 770 times and these 770 samples must be transmitted during the time allotted for a single channel in a frame. Utilizing the seven bit code requires the transmission of 5390 bits in this period. There has also been provided 21 additional bits per data channel which may be used for TTY, low speed data, or any order wire function. Since it is not possible for a transmitting station to position its transmission exactly in the time period assigned to it, a guard time equivalent to 34 bits is allowed between each channel. As will be shown later, this is equivalent to almost 43 microseconds or 13 kilometers of range to the satellite. It is necessary for the receiving station to acquire the carrier from a particular station at the beginning of its transmission, synchronize its bit clock, and detect the beginning of the information bit stream. Some 255 bits per channel are reserved for these functions. The bit requirements of each data channel are summarized in Table 1.

TABLE 1 - Bit Requirement per Data Channel

Information (770 samples @ 7 bits/sample)	5390 bits
Order Wire, etc.	21 bits
Carrier acquisition, bit and channel synchronization	255 bits
Guard	34 bits
Total	5700 bits

The bit-rate required for this system based on the above allocations is 7.98×10^5 bits/second.

The teletype channel requires no acquisition or synchronization allowance and there is no necessity for a guard space ahead of the frame sync (it is tacitly assumed that the TTY signal is generated by the master station). Therefore, a time equivalent to 5445 bits or 6.82 milliseconds is assigned to this channel.

The bit rate and the frame rate are derived by the master station from a stable 800 kHz source. At the beginning of each frame the master station transmits a suitable sequence to allow each station in the system to synchronize the bit rate generators and to identify the channels in the frame. A period of 255 bits is allowed for this function.

The frame synchronization signal (255 bits), the teletype channel (5445 bits), 13 channels at 5666 bits each (73,658 bits), and 13 guard spaces of 34 bits each (442 bits) account for all 79,800 bits per frame that are available.

Figure 4 shows how a transmitting station fits its transmission into the frame and how the receiving station extracts it. The analog signal is sampled at a 7.7 kHz rate and each sample is coded into a 7 bit digital word. The digital signal is read into a storage device at a 53.9 kHz bit rate and when ordered by the synchronizing signal, 770 of these digital words are read out of the storage at a 798 kHz bit rate for transmission through the assigned time slot. A storage capacity of 770 words is required for the signal to be transmitted in one frame by one station. A 1024 word storage device would, therefore, provide a comfortable margin in capacity. A similar storage device is required at the receiving station but in this case the signal is read into the storage at a 798 kHz bit rate and read out at a 53.9 kHz bit rate. The signal is then converted from a digital to analog form. As can be seen from Figure 4 the signal is subject to a delay equal to the period of one frame or 100 milliseconds in addition to the propagation delay.

To fit its signal into the proper time in the frame it is necessary for the transmitting station to have prior knowledge of the range to the satellite. With this information the propagation delay to the satellite can be taken into account in determining the proper time for the transmission of the signal from the ground. The transmitting station will first transmit only the 255 bit synchronizing signal at such a time so that it will appear in the center of the time slot assigned. The time is gradually advanced until this signal appears at the beginning of the assigned time slot at which time the information bit stream can be transmitted.

C. Communications Summary

The system implemented per the above for SOMS makes available at least 13 simplex 3.85 kHz data channels on a full-time basis. The link is sized to operate with a margin of 3.09 db above the R.F. threshold of approximately 9.3 db. The teletype channel has a margin of 4 db above a 7 db R.F. threshold. The scanner channel has a basebandwidth of 60 kHz, with an output signal-to-noise ratio of at least 30 db video (peak to peak) to rms noise, and operates with a 3.8 db margin above an R.F. threshold of 7 db.

The frequencies chosen for the SOMS were placed in the 7200-7250 MHz band for ground-to-spacecraft and in the 1690-1700 MHz band for spacecraft-to-ground. For operational simplification, both command and telemetry functions are within the above bandwidths. The frequency choices used for this study are given below:

Ground to spacecraft	7233.48 MHz
Command	7225 MHz
Spacecraft to ground (voice-type communications)	1695 MHz
Spacecraft to ground (teletype-only channel)	1693.6 MHz
Spacecraft to ground (scanner)	1697 MHz
Beacon	1691 MHz

Based on the above design objectives and frequency choices, the following spacecraft-to-ground communications parameters were chosen: 12 watts of transmitter power and transmitting antenna gain of at least 4.5 db over any angle 6^{o} or less from the maximum. This required spacecraft antenna gain is the same as that of the existing HS-303A antenna. The corresponding ground station requirements for the master and hub stations of the system are that aperture size be at least 30 feet in diameter and that the overall system noise temperature be no greater than $150^{o}K$. These ground station parameters are similar to those being used for the HS-303A system, except that the system noise temperature is lower in HS-303A. The low cost ground station for receipt of one teletype channel requires an aperture size of only 6 feet and an overall system noise temperature of $600^{o}K$.

The corresponding ground-to-spacecraft communications parameters were chosen as a minimum of 3.3 kw transmitter power in conjunction with a 30 foot antenna aperture. The spacecraft receiving system was assumed to have a noise figure of 6 db.

The above system, as sized after making the frequency and modulation method assumptions, results in the achievement of at least a 13 channel simplex TDM communications, one teletype channel for use from master station to small receiving terminal system, plus a means by which the scanner data is transmitted to all stations in the system with 30 foot antenna apertures. It is to be noted that all of the operational ground-to-spacecraft and spacecraft-to-ground frequencies for this system are placed in the same general bands. Thus, once the spacecraft is placed on station, only frequencies in the 7.2 and 1.7 GHz bands will be used. A 136 MHz telemetry backup and prime tracking capability is supplied in the spacecraft, but is not implemented at any of the SOMS ground stations, since its primary purpose is to serve as a means of STADAN tracking during the injection phase of the mission.

Simplified link calculations for this system are given in Table 2.

TABLE 2 - Link Calculations

	Up Link		Down Link			
	Commun.	Command	Commun.	Commun.	Scanner	Beacon
Transmitted Frequency(MHz)	7233.48	7225.00	1695.00	1693.60	1697.00	1691.00
Transmitted Power (watts)	3.3kw		8.6	8.6	2.0	0.120
Transmitted Power (dbw)	35.21		9.34	9.34	3.0	-9.2
Net Xmit. Ant. Gain (db)	54.15		4.5	4.5	4.5	4.5
Path Loss (@ 7.5° elevation) (db)	-201.86		-189.27	-189.27	-189.27	-189.27
Misc. Losses (db)	-6.75		-1.55	-1.45	-1.55	-1.55
Receiving Antenna Gain (db)	2.5		41.55	27.55	41.55	41.55
Received Carrier Power (dbw)	-116.75		-135.43	-149.43	-141.77	-153.97
Total Receiver Noise Temp. (°K)	870		150	600	150	150
Receiver Noise Bandwidth (MHz)	7.0		N.A.	.011	.267	
Receiver Noise Power (dbw)	-130.75		N.A.	-160.43	-152.57	
Predetection Carrier/Noise Power (db)	+14.0		N.A.	+11.0	+10.8	
Receiver Noise Density (dbw/Hz)	N.A.		-206.84	N.A.	N.A.	-206.84
Bit Length (μs)	1.252		1.252	6820	N.A.	
Received Bit Energy/Noise Density (db)	N.A.		12.39	N.A.	N.A.	
Post-Detection Noise Bandwidth - Video	N.A.		N.A.	N.A.	60 khz	
- TTY	N.A.		N.A.	1.0 kHz	N.A.	
- Sunpulse	N.A.		N.A.	N.A.	5 kHz	
Output Signal/ Noise Power (db) - Video	N.A.		N.A.	N.A.	30.0	
- TTY	N.A.		N.A.	39.2	N.A.	
- Sunpulse	N.A.		N.A.	N.A.	46.0	
Threshold (db)	10.0		9.3	7.0	7.0	
Margin (db)	4.0		3.09	4.0	3.8	

D. HS-303A Spacecraft Description

With the previously mentioned exceptions, the spacecraft considered in this study can be made quite similar to the HS-303A. This spacecraft is an outgrowth of the smaller spin stabilized synchronous spacecraft used in the Syncom and Early Bird programs.

The HS-303A spacecraft is made up of a 56 inch cylindrical structure which is 26¼ inches in height. The outside of the cylinder is covered by approximately 12,000 solar cells. Weight of the payload-apogee motor combination is estimated to be 352 pounds at launch and 160 pounds in orbit.

The apogee injection motor for the HS-303A is the Aerojet General Pathfinder solid fuel motor, with a maximum thrust of 3000 pounds and 19.5 seconds burning time.

The control system is an upgraded version of the Syncom-Early Bird system, consisting of two independent H_2O_2 systems. The HS-303A version is capable of providing a total velocity increment of 676 feet per second.

Communications requirements of the HS-303A are fulfilled by two redundant quasi-linear repeaters with 125 MHz bandwidth and a 6 db noise figure. The final power amplifier of the transmitter consists of four 6 watt travelling wave tubes. 1, 2, 3, or 4 of these tubes may be turned on in parallel, affording a choice of 6, 12, 18, or 24 watts of transmitter output. The receiving antenna has a gain of 4 db. The transmitting antenna has 5 db gain over a beam width of 6° off center in the direction looking toward the earth. Frequencies for the unmodified HS-303A spacecraft are in the normal commercial communications bands of 6 and 4 GHz. The ground to spacecraft frequencies (one for each repeater) are in the 6 GHz band; the spacecraft to ground frequencies are in the 4 GHz band. Two beacons, one for each repeater, are also in the 4 GHz frequency band.

Telemetry for the HS-303A consists of two PAM/FM/PM encoders carrying approximately 10 spacecraft data items plus command verification information. The spacecraft carries two 1.8 watt, 136 MHz transmitters as one means of transmitting this information to the ground. The telemetry data can also be transmitted to the ground via the 4 GHz beacons of the communications system.

Commands for the HS-303A are injected into the spacecraft in the 6 GHz band. Each repeater is associated with a command decoder, resulting in full redundancy for this subsystem.

The Solar cell array (12,240 N- on-P solar cells) supplies over 100 watts of power to the HS-303A immediately after launch, with approximately 10% degradation estimated to occur over the 5 year lifetime of the spacecraft. Sufficient nickel-cadmium batteries are supplied in the spacecraft to power three of the travelling wave tubes and both repeaters through spacecraft eclipses.

In this section, we have described the HS-303A spacecraft. The actual implementation of an SOMS as a result of this study is given in the following section, with the unique meteorological and communications features using concepts described in earlier sections of this report.

E. SOMS Spacecraft Description

In addition to the obvious differences from the HS-303A design caused by the addition of cameras and the choice of the communications system, certain additional changes have been made to the HS-303A.

The spacecraft structure was found to need space for mounting the cameras and additional openings in the solar array to accommodate the viewing areas for the cameras. With these relatively minor changes, the HS-303A structure can be modified to perform the SOMS mission.

A conservative weight estimate for the SOMS indicates an overall separated weight of 382 pounds. This weight can be placed into the proper transfer orbit by the Delta vehicle and is thus considered acceptable for the mission.

The Aerojet General apogee motor can be used for the SOMS mission with no changes from the HS-303A configuration.

The power supply subsystem for the SOMS mission carries less solar cells than the HS-303A, in view of the requirement for camera openings in the solar array. The number calculated for this study is 11,640 cells, as opposed to the 12,240 used on the HS-303A. The battery complement for the SOMS has been reduced from 25 to 11 pounds in view of the decision not to require SOMS operations during the twice-yearly eclipse periods. This ground rule allows the usage of 1.75 ampere-hour battery cells in place of the 4.45 ampere-hour batteries used on the HS-303A. The end result of the above design modifications is a power supply system which can support the camera power requirements plus communications power requirements with two travelling wave tubes operating. Thus, the required 12 watts of spacecraft transmitter power is available. If the use of the 136 MHz for telemetry and tracking purposes is mimimized after the first few days in orbit, there should be no problem in supporting the required load for at least two years after launch.

The spacecraft cameras are additions to the original HS-303A. Their technical characteristics have been covered previously and will not be repeated here.

The spacecraft communications system consists of two redundant transponders required to carry out the airborne requirements of the TDM communications system. Either one of the transponders (using two of the four travelling wave tubes) will furnish the required 10 MHz R.F. bandwidth with receiver sensitivity and transmitter power sufficient to carry out the needs of the communications link. An additional design constraint is the requirement that the transponders be coherent in order to be compatible with the NASA-GSFC range and range-rate system. This system will only be used in the SOMS program if it is found that ground station 1690-1700 MHz angle and range tracking plus STADAN 136 MHz tracking do not allow the generation of sufficient orbital information to supply the tracking needs of the mission. Since both Early Bird (Intelsat I) and HS-303A (Intelsat II) are carrying out their missions without the use of a range-range-rate system, it is not believed necessary for SOMS to implement such a system. However, the capability will exist in the transponders to accommodate the system at SOMS frequencies, if it should be proven desirable at a later date.

Relative to the tracking, telemetry, and command functions of the spacecraft, it is intended that an expansion of HS-303A capability be utilized to carry out these items. Tracking during the early portion of the mission will be accomplished by means of both 136 and 1691 MHz beacons. After the spacecraft is on station, only the S-band beacon will be used. Telemetry will be an expansion of HS-303A capability in that 15 data inputs will be required. In addition, five data channels will be required for command verification. The existing method of transmitting sun-pulse and execute data to the ground will be included in the system. The same basic transmitting system used on the HS-303A will be adequate, allowing the telemetry link to be carried down on the 1691 and/or the 136 MHz frequencies. It is anticipated that only the 1691 MHz frequency will be used for operations once the spacecraft is placed on station. The 136 MHz telemetry capability will exist as backup after that time, although it is not anticipated that it will be necessary to implement 136 MHz ground equipment at the several ground stations postulated for this study. Any necessary 136 MHz capability can be implemented more economically at the STADAN sites. As in the telemetry case, the command requirements of the SOMS can be accommodated by expanding the present HS-303A design to give the capability of handling 24 commands. Command will be at the 7225 MHz frequency, with ground station command capability being made available only at the master stations of the system.

The controls system of the SOMS will be the same as that planned for the HS-303A except that a low threshold (0.002°) nutation damper will be added.

F. SOMS Ground Stations

The several ground stations required for the SOMS mission are of three basic types.

The first of these is a master station (one required for each spacecraft in orbit), which is capable of sending commands to and receiving telemetry from the spacecraft, tracking the spacecraft, setting the synchronization for one spacecraft-ground station system, receiving camera information from the spacecraft, plus transmitting and receiving various forms of meteorological data via the spacecraft. This type of ground station is known as CDAT (command-data acquisition and transmit) terminal. It consists of a 30 foot antenna aperture having 3.3 kw communications and command transmit capability, with an overall system noise temperature of 150°K.

The second type of terminal comprises most of the hardware required for the CDAT terminal. Since its capability need not be as great as that required of the CDAT terminal, its design is simplified wherever possible in order to minimize costs. This second type of terminal will have the capability of receiving camera information from the spacecraft, plus that of transmitting and receiving meteorological data via the spacecraft. This type of terminal is defined as a DAT (data acquisition and transmit) terminal. It consists of a 30 foot antenna aperture with 3.3 kw communications transmit capability, plus an overall system noise temperature of 150°K.

The third type of terminal is capable only of receiving one slow-speed teletype channel from the spacecraft. This type of terminal is defined as a DA (data acquisition) terminal. It consists of a 6 foot antenna aperture and an overall system noise temperature of 600°K.

In laying out the ground terminals for this study, the basic assumption was made that the system would consist of two spacecraft, located at 50°W. longitude and 150°W. longitude. To economize on ground station costs without requiring the use of redundancy in the stations, two master stations were located in mid-United States, i.e., at Brownsville, Texas. One of these master stations works with the Atlantic Ocean spacecraft, and one with the Pacific Ocean spacecraft. In case of failure of one master station, the other could still work both spacecraft on a time sharing basis.

DAT ground stations to supply the needs of the overseas meteorological centers are located for purposes of this study near Offenbach, Germany and Brasilia, Brazil for Atlantic coverage. Overseas ground stations are located in the general vicinity of Melbourne, Australia and Tokyo, Japan for Pacific coverage. Additional stations could be added, as required, in each sector as long as the overall voice-type communications capacity of the system is not exceeded.

The one DA ground station considered in this study is located in Hawaii. Since it is a receive-only station, it does not interfere with the operation of the several transmitting stations in the system. Therefore, as many of this type of station as may be desired can be added to the overall system.

If desired, receive-only ground stations using 30 foot antenna apertures and 150°K system noise temperature can be used at locations such as Hawaii in place of the austere DA station mentioned above. This type of station would essentially be a DAT station without transmit capability. Its cost would be slightly less than that of a full DAT station; its cost and receiving capability would naturally be greater than that of the DA station (using Hawaii as an example) covered in this study.

The approximate locations of the ground stations chosen for purposes of this study are given in Table 3. The basic capability of the three types of ground stations is shown by Table 4. Range, azimuth angle, and elevation angle from each ground station to the appropriate spacecraft is shown for the assumed spacecraft orbital locations in Table 5. Block diagrams of the system and three basic ground station terminals (CDAT, DAT, and DA) are given in Figures 5, 6 and 7.

TABLE 3 - Station Locations

Brownsville, Texas	97.5° W, 25.8° N
Toowoomba, Australia	152.2° E, 27.7° S
Juo-Machi, Japan	140.8° E, 36.4° N
Honolulu, Hawaii	157.8° W, 21.2° S
Brasilia, Brazil	48.0° W, 15.8° S
Offenbach, Germany	8.8° E, 50.2° N

No provision for Moscow, Nairobi, New Delhi at this time.

Spacecraft at 50 and 150° W.

TABLE 4 - Ground Station Capability

Brownsville, Texas		
	2	30' antenna - transmit & receive
		telemetry - at 1691 MHz
		command - at 7225 MHz
Toowoomba, Juo-Machi, Offenbach, Brasilia		
	1	30' antenna - transmit & receive
		No telemetry
		No command
Hawaii		
	1	6' antenna - receive only
		No telemetry
		No command

TABLE 5 - Spacecraft Ground Station Parameters

Spacecraft located at 50^{o} West

Station	Range (km)	Azimuth	Elevation
Brownsville, Texas	38,612	111.7^{o}	29.9^{o}
Brasilia, Brazil	36,068	352.7^{o}	71.3^{o}
Offenbach, W. Germany	40,490	245.1^{o}	10.8^{o}

Spacecraft located at 150^{o} West

Station	Range (km)	Azimuth	Elevation
Brownsville, Texas	39,029	251.2^{o}	25.4^{o}
Juo-Machi, Japan	40,795	102.7^{o}	8.0^{o}
Honolulu, Hawaii	36,353	159.3^{o}	65.3^{o}
Toowoomba, Australia	39,564	74.0^{o}	19.9^{o}

G. Vehicle

The launch vehicle for the SOMS consists of the three-stage, thrust-augmented Model DSV-3E Delta vehicle. The first stage consists of the Thor booster with three solid-propellant rocket motors strapped to the booster. The second stage consists of the "fat tank" configuration with a 380 second burning time. The third stage required for the SOMS is the TE-364, since the FW-4D third stage used for HS-303A cannot accomplish the proposed mission.

The use of the TE-364 in place of the FW-4D is the only vehicle change required from the HS-303A Delta configuration to meet SOMS program objectives. This was necessary because the Delta configuration with the FW-4D third stage cannot accommodate the anticipated SOMS spacecraft/apogee motor combination. This follows from the fact that the maximum spacecraft/motor weight which can be boosted into equatorial synchronous orbit by use of the FW-4D third stage is 360 pounds (the latest estimated HS-303A total weight is 352 pounds). Since the present estimated SOMS spacecraft/motor weight at third stage separation is 382 pounds, an improved vehicle combination is required.

The proposed Delta combination, with the TE-364 third stage, is capable of placing approximately 450 pounds in equatorial synchronous orbit. Thus, the use of the TE-364 will allow the mission to be achieved with a large weight margin,approximately 70 pounds. The proposed Delta combination will have been flight-tested on the RAE (Radio Astronomy Explorer) during the 3rd calendar quarter of 1967.

The above vehicle configuration will allow mission accomplishment without the need for any change in the apogee motor presently being used on the HS-303A. This minimizes the mandatory redesign in converting the HS-303A spacecraft to the SOMS configuration if it is decided to use this HS-303A as the nucleus of the SOMS design.

IV. SPACECRAFT SUBSYSTEMS

A. Meteorological Equipment

The SOMS will use a modified version of the spin-scan cloud scanner being flown on ATS-B (Figure 8) to obtain daylight cloud-cover pictures.

The SOMS version of this camera scanner will contain a high-resolution Cassegrain telescope with a pinhole aperture followed by a photomultiplier tube. A video raster generated in the east-west direction by the satellite spin, and in the north-south direction by mechanical tilting of the telescope's optical axis in discrete steps from +8.0 to -8.0 degrees, provides earth coverage from approximately 57.4° North latitude to 57.4° South latitude and from the west limb to the east limb in longitude. This area is covered by 2000 horizontal (west-to-east) TV lines. Ground resolution of this system at the subsatellite point is approximately 2.71 nautical miles. Total scanner weight is estimated as 12 pounds; average power consumption during normal system operation is 8.8 watts.

A description of the ATS scanner is given in the following paragraphs. Figure 9 is a diagram of the scanner optical system. A parabolic primary mirror with a 5-inch diameter and a 10-inch focal length, used with a flat secondary mirror, produces an image on the face of an aperture plate. The 0.0001-inch-diameter aperture provides an angular resolution of 0.1 milliradian. The instantaneous optical field-of-view from synchronous altitude is, therefore, 1.94 nautical miles. Both the primary and secondary mirrors are made of fused quartz to provide optimum temperature stability.

Proper focusing of the f/2 parabola is critical; the focal plane cannot be allowed to move from the aperture plate. To enable the optical system to retain focus throughout the expected temperature range, the basic mirror-mounting surface has been fabricated from Invar, which has a temperature-expansion coefficient very close to that of quartz.

The lower wavelength response limit of the system is set by a haze filter with 5-percent transmission at 460 millimicrons and 50-percent transmission at 485 millimicrons. The long wavelength cutoff is established by the spectral response of the photomultiplier S-11 photo surface.

Defocusing of the image from the aperture over the full active area of the photomultiplier photocathode assures photocathode loadings that will not affect photocathode sensitivity over the life of the system. Even the focusing of direct sunlight on the aperture plate will not overload the photocathode.

The telescope-photomultiplier assembly is mounted to the scanner frame by two Bendix flexural pivots located at the center-of-gravity of the telescope-photomultiplier assembly (Figure 10).

The mechanical drive mechanism, which is hermetically sealed, consists of a 90-degree-per-step stepper motor driving a 10.4-to-1 reduction gear which in turn advances a 40 thread-per-inch lead screw. This simple conversion from rotary to linear motion advances the telescope in the order of 0.0006 inch per scan line. A bellows configuration at the movable push rod of the drive mechanism provides a hermetic seal. Two stainless steel straps transmit linear motion from the scanner frame to the telescope assembly. Figure 11 shows the complete scanner and the drive configuration.

A command from the ATS spacecraft phased-array control electronics (PACE) system causes the scanner drive mechanism to advance one step per spacecraft spin. When the step mechanism has completed the required 2000 steps, a limit switch initiates retrace. Substituting a 17-cps oscillator output for the PACE input, and reversing the sequence of the step-motor phase, causes the telescope to return to the 50° North latitude position in approximately 2 minutes. At this point, the opposite limit switch signals the return to normal north-south stepping in synchronism with spacecraft rotation.

Scanner electronics include the video amplifiers and buffers, the photomultiplier high-voltage supply, the command logic and retrace oscillator, the stepper-motor drive circuits, and the telemetry-conditioning circuits. All these circuits (except the high-voltage supply) are located on two circuit boards mounted in the frame assembly (Figure 12); one board is mounted parallel to, and the other at right angles to, the telescope optical axis. The high-voltage supply, packaged as a module, is mounted directly to the scanner frame.

The ATS scanner also contains an adder in the video chain to add the sun pulse from the ATS sun sensor to the video information. Composite output from the scanner is 1 volt peak-to-peak with the sun pulse positive-going and the video negative-going. Output impedance of the video output stage is 75 ohms. Two such outputs are provided, one having a 10-db higher output level than the other. The bandwidth of these video outputs is 200 kHz.

The mounting surface of the ATS scanner is perpendicular to the telescope optical axis. Unit dimensions are 11 inches by 10 inches by 7.75 inches.

The scanner for SOMS will be a modified version of the ATS scanner. Table 6 compares system parameters of the ATS scanner with those of the proposed SOMS scanner.

Only minor changes in the existing scanner are proposed: reduction in scanner weight; a slight increase in the maximum tilt angle of the telescope; rotation of the mounting plane by 90 degrees. These changes and the minor changes in the electronics require initiation of the SOMS version of the camera at the prototype level instead of at the flight level.

Electrical interfaces between the proposed scanner and the spacecraft are:

1. Power (-24.5v unregulated)

2. Commands

3. Telemetry

4. Sun pulse input

5. Video outputs (two)

Because the spacecraft power bus will supply unregulated -24.5 volts to the scanner system, a voltage regulator must be included as part of the scanner electronics. The average power consumed by the system should be no more than 8.8 watts if a regulator efficiency of 80 percent can be attained.

The nine ground commands required to ensure proper operation of the system are:

TABLE 6 - Parameters of ATS and Proposed SOMS Scanners

Parameter	ATS Scanner	SOMS Scanner
Field-of-view (N-S)	15 degrees	16 degrees
Earth coverage (N-S)	50° N lat. - 50° S lat.	57.4° N lat. - 57.4° S lat.
(E-W)	East to west limb	(unchanged)
Resolution	2000 TV lines	(unchanged)
Instant optical field-of-view	0.1 milliradian	(unchanged)
Telescope step amplitude	0.131 milliradian	0.1395 milliradian
Ground resolution		
At subpoint	2.54 n.m.	2.71 n.m.
At zenith	5.05 n.m.	6.95 n.m.
Zenith angle	58 degrees	65.4 degrees
Video bandwidth	200 kHz	60 kHz
System S/N	30 db minimum	(unchanged)
Power Input	-24.0 v. regulated	-24.5 v. unregulated
Dynamic range	10^4 to 100 ft. lambert	(unchanged)
Gain (video)	Set	Variable by command
Housekeeping - telemetry	6 outputs	10 outputs
Ground commands	6	9
Approximate size	8 x 10 x 11 in.	(Basically unchanged)
Power consumption	6.5 watts	8.8 watts
Weight	15.5 pounds	12 pounds
Mounting plane	Perpendicular to optical axis	Parallel to optical axis

1. Subsystem power ON - connects unregulated -24.5 v to the subsystem.

2. Subsystem power OFF - disconnects unregulated -24.5 v from the subsystem.

3. Normal scan mode - causes the camera to scan normally from north to south and retrace at increased speed.

4. Back-to-back scan mode - causes the camera to scan normally in both directions (no retrace at increased speed).

5. South limit override - causes the system to begin scanning from south to north from the point at which the telescope was directed when the command is received.

6. North limit override - causes the system to begin scanning from north to south in the same manner as described for the previous command.

7. High gain - sets optimum video gain for low scene illumination.

8. Medium gain - sets optimum video gain for medium scene illumination.

9. Low gain - sets optimum video gain for high scene illumination.

Outputs of the five digital and five analog telemetry channels required for housekeeping purposes are:

1. Scan mode T/M - a digital output indicating normal or back-to-back scanning.

2. Scan direction T/M - a digital output indicating the direction of scan.

3. Telescope temperature (hot) T/M - an analog output indicating the temperature at the warmest point in the telescope assembly.

4. Telescope temperature (cold) T/M - an analog output indicating the temperature at the coldest point in the telescope assembly.

5. Power input T/M - an analog output indicating input power level.

6. Scanner pressure T/M - a digital output indicating that the mechanical drive mechanism is retaining pressure.

7. High voltage supply T/M - an analog output indicating output level from the photomultiplier power power supply.

8. Video output T/M - an analog output monitoring video output from the camera.

9. & 10. Video gain T/M - two digital outputs indicating the video gain setting commanded into the system.

The scanner system will use the sun-pulse from the satellite sun sensor to advance the mechanical drive mechanism. The sun pulse will also be added to the video output signal from the scanner. Two identical composite video outputs will be buffered for isolation, and the output stages will be made short-circuit-proof. The output amplitude will swing from +0.2 volt to -1 volt with the video information swinging negative from zero and the sun pulse swinging positive. The output stages will both have a 75 ohm output impedence. Figure 13 is a block diagram of the proposed scanner, and Figure 14 shows the composite video output format.

To prevent degradation of system resolution by more than 15 percent (worst case) from the combined effects of spacecraft spin-axis attitude errors, the line-to-line (that is, spin-to-spin) orientation error of the spacecraft spin axis must be held to less than 0.0019 degrees during scanner operation. The ATS scanner has consistently demonstrated a capability of stepping across the raster with line-to-line errors of 10 percent of one linewidth or less.

Assuming that the spacecraft position will not drift in the north-south direction from the equator, a spin-axis attitude-control accuracy of ± 0.7 degrees will assure a minimum north-south coverage from 50° North to 50° South latitude. Assuming no spin-axis attitude error, a spacecraft position drift of ± 7.4 degrees (error measured from local vertical at the equator) will assure the same minimum coverage. If both these errors are present, the error allowable to each must be determined by trade-off between attitude-control capabilities, spacecraft-positioning capabilities, and allowable loss of picture data.

The bench checkout equipment required to support the SOMS scanner before the subsystem is installed in the spacecraft consists of a spinning target like that used to ground-test the ATS scanner, a display monitor, a command panel, and a -24.5 v. power source. The total equipment required should not fill more than two standard equipment racks. After the scanner is installed in the spacecraft, the target simulator would continue to be used, and the bench checkout equipment could be used with the regular ground station display equipment for debugging and troubleshooting.

B. Transponder

This section describes the design of the transponder proposed to fulfill the requirements of this program. Individual components of this transponder will be similar to those used in programs such as Syncom, Early Bird, and HS-303A, and the descriptions of the individual blocks will emphasize these similarities.

Characteristics of the redundant transponders in the SOMS satellite system are:

1. Receive antenna gain, 2-1/2 db
2. Receive at 7.23348 GHz
3. Receiver noise figure less than 6 db
4. 7-MHz noise bandwidth
5. 12 watts output
6. Communication transmit at 1.695 GHz
7. Scanner and sun sensor transmit at 1.697 GHz
8. Net transmitting antenna gain, 4-1/2 db at 6 degrees off center
9. Beacon power output, 120 milliwatts
10. Beacon frequency, 1.691 GHz

Figure 15 is a block diagram of the proposed redundant transponder. The portion within the dotted line is duplicated for the second transponder electronics and is not required in the figure.

The total required gain of the transponder may be determined from the foregoing performance specifications and from the requirement that the transponder, in the worst case, must operate at an input carrier-to-noise power ratio of +10 db. The input noise power is given by:

$$N_t = KT_sB$$

where: N_t = total input noise power in watts
K = Boltzmann's constant in joules/^{o}K
T_s = system noise temperature in ^{o}K
B = noise bandwidth in Hz

Substituting in the above equation yields an input noise-power level of -100.8 dbm. Because the carrier level must be at least 10 db above the noise level, the input signal level must be at least -90.8 dbm. The required net gain is then 40.8 + 90.8, or 131.6 db. The following tabulation of component gains (or losses) shows that the proposed transponder design is feasible:

Component	Gain db
Tunnel diode amplifier (4 each @ 12.5 db/stage)	+ 50.0
Hybrid 1	- 3.0
I.F. amplifier and limiter	+ 47.6
First mixer	- 7.0
Resistive adder	- 4.0
Up converter	- 6.0
Driver traveling-wave tubes (TWT)	+ 30.0
Hybrid 2	- 3.0
Hybrid 3	- 3.0
TWT gain (saturated)	+ 30.0
NET GAIN	+ 131.6 db

Detailed Description

Receiving Antennas: The design of the two receiving antennas will be based on those for the HS-303A satellite which were designed to operate at approximately 6300 MHz and, because of the design technique, may be easily scaled to the 7250-MHz band.

Receiving antenna 1 is a 3-element cloverleaf array. The polarization is horizontal linear, perpendicular to the spin axis. The cloverleaf element is basically a horizontal loop. In the actual antenna, this loop is approximated by a cluster of four halfwave curved radiating elements arranged in the pattern of a four-leaf clover and fed from a common coaxial line. The cloverleaf elements are fabricated by investment casting. The 3-db beamwidth is approximately 36 degrees. Average gain around the spin axis, measured at the feed-line input at the base of the antenna, is approximately 2.5 throughout the angular region of $\pm$ 6 degrees from broadside.

Receiving antenna 2 is a fin-fed slot antenna consisting of four longitudinal slots on a cylinder fed by fins. The fins are coupled to a coaxial transmission line that passes through the center of the cylinder. This type of antenna is used because of the additional structural rigidity required to support the receiving antenna 1. Performance characteristics of this antenna are similar to those of antenna 1.

The requirement for two separate receiving antennas results from the fact that the noise temperature of the system is set by the tunnel diode amplifiers (TDA); a single antenna followed by a hybrid feeding the TDA's would incur a 3-db signal-to-noise ratio loss, which could not be made up with amplification.

Transmitting Antenna: The design of the proposed signal transmitting antenna is based on the design of the Syncom and HS-303A antennas. Specifically, the antenna is a five-element collinear slot array with vertical linear polarization which is parallel to the spin axis, and therefore orthogonal to the polarization of the receiving antennas. A tapered distribution of the element excitation is used to broaden the beam to meet a net gain requirement of 4.5 db at $\pm$ 6 degrees from broadside around the spin axis. This tapering results in a 3-db beamwidth of 18 degrees.

Transponder Electronics: The input signal from the antenna is fed through a 7.2 GHz filter which rejects spurious signals outside the passband. The signal is then amplified by four cascaded germanium tunnel diode amplifiers to provide approximately 50 db of gain. Noise figure of the amplifier is approximately 6.0 db. The design of these amplifiers is based on the design of the HS-303A amplifiers which attained a noise figure of 5.5 db at 6.3 GHz.

The output of the last TDA is fed to a hybrid where the signal is split into two channels. One output is fed to the command receiver and the other is fed to the communications down-converter through a bandpass filter. The design of the command receiver is based entirely on that used in the HS-303A.

The communications signal from the output of the bandpass filter is fed to a crystal mixer down-converter. The local oscillator operates at a frequency of 7305.12 MHz, and the communications signal is 7233.48 MHz; the local oscillator is therefore on the high side of the incoming signal at a difference frequency of 71.64 MHz.

The output of the mixer is fed to an I.F. amplifier-limiter combination. The amplifier, centered at a frequency of 71.64 MHz with a 3-db bandwidth of 7 MHz, has a maximal flat response with the 0.1-db bandwidth of at least 1.4 MHz. The output of the I.F. amplifier drives the limiter. Full limiter improvement must be achieved at carrier-to-noise ratios of 10 db; otherwise, a loss in output signal-to-noise ratio will result. This requires that the bandwidth of the limiter be large and that its linear transfer characteristic be extremely small relative to the drive level.

The limiter is followed by a bandpass filter centered at 71.64 MHz which suppresses all harmonics generated by the limiter.

The output of the bandpass filter drives one input of the resistive adder.

The output of the voltage-controlled oscillator (VCO) drives a cascaded limiter and bandpass filter. The output of the filter drives one input of the resistive adder. The VCO operates at a nominal frequency of 73.64 MHz. When driven by the sum of the output of the scanner and the sun sensor, the VCO will deviate from nominal by approximately 150 kHz peak-to-peak. This VCO will be similar to the one being developed for the scanner experiment on ATS-B; the major revision will be a change in operating frequency (65.39 MHz) and deviation (10 MHz).

The remaining input to the resistive adder is the phase-modulated beacon at a frequency of 67.64 MHz.

The output of the adder is fed to a high-level mixer which is also driven by the 1623.36-MHz local-oscillator signal. The sun frequencies (1691.0, 1695.0 and 1697.0 MHz) are filtered by the bandpass filter and fed to the driver TWT. The high-level mixer will be based on the design developed for Syncom, since the frequencies are nearly the same (1815 MHz); however, the power level required for the high-level mixer (0.5 mw) is less than that required for Syncom (2.5 mw).

A driver TWT is used to receive the output of the bandpass filter in this design because the drive level required at the input to hybrid 2 to properly drive the output TWT's is approximately 48 milliwatts. Although increasing the saturated gain of these TWT's to 40 db (from the nominal 30 db) would make it possible to eliminate the driver TWT, increasing the gain is not proposed because this would require a longer and heavier slow-wave structure than that required to achieve 30-db gain. However, the tube developed for the output stage of Syncom is proposed for use as the driver TWT.

The output of the driver TWT is fed to hybrid 2, which is also fed by the output of the driver TWT in the transponder 2 electronics package. The power is further split in hybrid 3 and hybrid 4 until it is finally fed to the output TWT's.

Design of the output TWT's (nominal 30-db gain at saturation and maximum output power of 6 watts at 1695 MHz) is based on that successfully demonstrated in the Syncom and Early Bird communications satellites. Overall efficiency of the tubes is 26 percent with a mean time between failure (MTBF) at 90-percent confidence of 46,600 hours, values identical to those of the Hughes 314-H, 2.5 watt S-band TWT (Syncom tube).

Each output TWT is activated by a unique command. Due to a limitation of prime power, only two TWT's may be operated simultaneously; however, any combination of two may be selected thereby increasing the reliability of the output package.

The output of each TWT drives a bandpass filter centered at 1695 MHz to suppress harmonically related frequency components generated in the TWT. The output of each bandpass filter is fed to a ferrite switch similar to that developed for the HS-303A program.

The output of both switches is summed in the output hybrid connected to the transmitting antenna. Cable lengths between the TWT's and the switches are adjusted to compensate for differences in phase shift through the TWT's.

As the designs of the oscillator multiplier chains are similar, only the receiver local-oscillator chain will be described.

The master oscillator and buffer amplifier operate at a frequency of 67.64 MHz. The buffer-amplifier output feeds a coupler which in turn feeds a relatively low-level signal to the phase modulator; this signal when up-converted is the beacon. The other output from the coupler drives a transistor X3 multiplier whose output is bandpass-filtered at approximately 203 MHz. The filter output drives the hybrid, where the signal is split into two paths: the up-converter chain and the receiver local-oscillator chain. The output of the hybrid to the receiver local-oscillator drives a step-recovery X9 multiplier whose output feeds a bandpass filter centered at 1827 MHz. The signal is then fed through two cascaded X2 varactor multipliers, using isolators for decoupling, and finally through an isolator to the first mixer. The frequency at this point is 7305.12 MHz. The design for these circuits has been well established during the Syncom, Early Bird, and HS-303A programs.

C. Telemetry and Command

The planned approach to meeting SOMS telemetry and command requirements is to rely on hardware used successfully in previous synchronous satellites.

The trend has been to rely less on VHF command and telemetry frequencies and to use the SHF bands for these functions. The SOMS concept follows this trend to the extent of putting both command and telemetry in the SHF bands; in addition, the telemetry will also be available in the VHF band. This makes 136 MHz available for STADAN tracking and enables the STADAN stations to receive telemetry as necessary. This approach will limit command capability to that available from the dual station at Brownsville, Texas but this should not create any system hardships.

The command subsystem will utilize the two microwave receivers of the dual transponder and the redundant pulse-tone operated decoders with associated switching circuitry to accomplish the desired command functions. The command link will operate at a radio frequency of 7225 MHz. Either decoder is capable of carrying out any of the spacecraft command functions.

As in the HS-303A, commands are accomplished in three steps:

enable, command, and execute. The enable tone precedes the command pulses for the purpose of turning on power to the command register. The pulse train carrying command information is then transmitted and confirmed via the telemetry link before the command execute signal is sent. After the command has been executed, the enable tone is again sent to return the command system to its original state.

The 7225 MHz tunnel-diode amplifier output of the spacecraft transponder is fed to a hybrid, one output of which goes to the command mixer through a bandpass filter and the other to the communications mixer. The intermediate signal from the mixer enters another bandpass filter, is amplified, and enters an LC discriminator.

The command system needs 15 basic commands to handle the SOMS; additional command requirements for the scanner will increase the estimated commands required to more than 15. The 4 x 4 matrix previously sufficient for command requirements in the HS-303A must therefore be changed to a 5 x 5 matrix, which will complicate the spacecraft hardware in the command decoder. However, the additional circuity (an additional flip-flop and set of matrix circuitry) required is quite simple. The system will therefore require six tones for all foregoing command functions. A total of 24 commands will be required to accommodate SOMS requirements:

Present HS-303A requirements	15
Cloud camera requirements	9
	24

When the execute tone is transmitted to the spacecraft, the output of the execute detector passes through a switch which has been previously set to pass the execute pulse by the enabling pulse. This switch supplies power to the 5 x 5 matrix, which has a unique output for up to 31 states of the command register. The matrix output turns on a driver which carries out the command function. Execution of the command continues only while the execute tone is present within the system. The telemetry encoder monitors the status of the command register whenever the command decoder is enabled. This allows command status to be viewed on the ground by reading the output of the five telemetered command logic channels.

A block diagram of the HS-303A command subsystem as modified for the SOMS mission is shown in Figure 16. The only required change consists of the inclusion of a 5 x 5 command matrix in place of the 4 x 4 matrix used for HS-303A.

The telemetry subsystem will operate through both the 136 MHz and 1691 MHz communications beacon bands. As the 136 MHz carrier will be operated for STADAN tracking only during the first few days after launch, spacecraft power can be conserved by leaving the 136 MHz carriers off after the spacecraft is placed on station. Therefore, the prime telemetry mode for SOMS operation will be through the communications beacon.

The telemetry subsystem consists of two VHF (136 MHz) transmitters, two PAM/FM encoders, a turnstile antenna, and two beacon (1691 MHz) telemetry circuits which interface with the spacecraft transponders.

The VHF system consists of two 1.8 watt transmitters, either of which may be frequency-modulated by one commutated channel, the two solar pulses (psi and psi-2) and the execute tone. In the HS-303A design, one commutator was used to sample twelve telemetry data and/or reference points consecutively. The frequency of the commutated channel is 14.5 kHz. The two solar pulses use frequencies of 9 and 10.5 kHz. The execute tone frequency is 12 kHz.

The 1691 MHz system operates from the same PAM/FM encoders as the 136 MHz system, with the only difference being that the high-frequency system works through either one of the spacecraft transponders. As stated above, it is anticipated that most telemetry will be obtained via the SHF frequency once the spacecraft is on station.

Basic techniques available from previous synchronous satellite missions can be used in designing the telemetry encoder. The additional information needs of the video scanners result in a requirement to telemeter more data. Present estimates indicate a need for 15 data inputs in addition to the continuing requirement for execute and sun-pulse information; five main data channels will also be needed for command verification. This compares to the total of 12 data and reference channels used in the HS-303A. The simplest method of implementing the additional requirements is to add a subcommutator to one telemetry data channel. The sampling time for the main data and command verification channels will be in the range of two to four seconds. The subcommutator sampling time will be approximately 60 seconds. Eleven data information points will be handled by the subcommutator. Anticipated telemetry requirements are:

Frequency	Function
9 kHz	Psi
10.5	Psi-2
12	Execute
14.5	Data and Calibration

Data and Calibration:

Main commutator	- 14.5 kHz
Spacecraft data	- 4 channels
Command verification	- 5 channels
Calibration	- 2 channels
Subcommutator	- 1 channel

Subcommutator

Scanner data	- 8 channels
Spacecraft data	- 3 channels

D. Power Supply

The HS-303A spacecraft power system has been evaluated for the purpose of converting the spacecraft mission from that of a communication system to that of an SOMS. The basic idea behind this conversion is to use off-the-shelf components and therefore the original HS-303A load demands are used to represent the meteorological load demands whenever similar loads are required.

For this study, the main solar array must be modified to allow for the openings necessary for the relocated control jets and the two scanner systems. The additional openings for the scanners cause a loss of approximately 14.5% of the optimum peak power available from the original main solar cell array. It is anticipated that this will result in an available power of 90 watts for the SOMS at a 90° sun angle. For a 66.5° sun angle, the available power drops to 77.5 watts. After two years in orbit, the available power at a 90° sun angle is expected to be 81 watts.

The conculsion drawn from the investigation of the power supply is that the HS-303A power system can be modified to support the proposed meteorological mission if some precautions are followed during operation. When the main solar array is at a sun angle of 66.5°, it will not support both VHF transmitters as well as one scanner and transponder. Under these loads, the batteries will have to carry that part of the load demanded by the VHF transmitters even when the spacecraft is fully illuminated. Since the scanner system rather than the solar array determines the attitude of the spacecraft, the solar array angle of 66.5° must be accepted as a worst case condition. It is not possible to operate the spacecraft from the solar array alone. The batteries are necessary to supply the 0.5 ampere pulses demanded by the scanner stepping motor. At a sun angle of 66.5°, the array will handle a maximum current load of 3.1 amperes before the voltage will drop below that necessary for the load regulators to stay in regulation. This means that only one VHF transmitter may be operated (2.870 amps + 0.215 amps = 3.085 amps) while the rest of the system is operating. After two years and at a sun angle of 66.5°, the solar array will support a maximum current load of 2.83 amperes before its terminal voltage drops below that necessary to sustain load regulation. This indicates that the solar array is not capable of handling the normal spacecraft load of 2.87 amperes without the use of batteries; therefore, in order to occasionally recharge the batteries the number of pictures taken per day will have to be decreased. On this basis, the batteries can be recharged.

Therefore, an operational mode whereby the VHF transmitters are not used when the scanner and transponder are being operated will allow successful operation of the proposed system. Since this is feasible after the spacecraft is on station, it is concluded that the desired operational results can be accomplished but with reduced operating time towards end-of-life of the system.

E. Controls Equipment

Gas Supply Requirements

The HS-303A is basically a scaled-up Syncom III with the baseplate diameter and weight approximately doubled. It carries double the amount of H_2O_2 fuel in eight tanks instead of four, and the attitude-control jet has been moved out to increase the moment arm. The ΔV capacity of the HS-303A is therefore approximately the same as that of Syncom III, some 600 fps, most of this being needed to correct for a 3-sigma error of the Delta launch vehicle. A reorientation maneuver of 50 degrees expends only 27 fps of the H_2O_2 capacity. Attitude control of the SOMS therefore requires no modifications of the HS-303A gas supply.

Control System Design

The HS-303A is a spin-stabilized cylindrical spacecraft with a nominal inertial ratio $\sigma = 1.42$. It uses a synchronized, pulsed, axial jet (parallel to the spin axis) to precess the spin axis. Sun sensors, used in conjunction with ground station processing equipment, control the jet firing. This system, proven on Syncom and Early Bird, should maintain the spin-axis attitude of SOMS to within $\pm$ 0.5 degrees of the orbit normal.

The only control system modification required for SOMS is the use of a nutation damper similar to that to be flown on the ATS-B. The SOMS mission will therefore not cause any appreciable change in the weight and power requirements of the HS-303A attitude control system.

Nutation Characteristics

The spin-scan cloud scanner will be flight-tested on the ATS spacecraft. A comparison of the nutation characteristics of the ATS and HS-303A spacecraft will be useful in applying the results of the scanner flight test to the SOMS mission.

The nutation frequency of ATS is nominally 1.1 times the spin rate, whereas that of the HS-303A is nominally 1.42 times the spin rate. On ATS, the maximum scan-line shift is 0.62 times the cone angle; on HS-303A, it would be 1.94 times the cone angle. Thus the maximum cone angle allowed for HS-303A is approximately one-third of the cone angle allowed on ATS.

F. Structure

The basic structure to be used shall be that of the HS-303A or equivalent, with scanners added to accomplish the requirements of the SOMS mission. Specific changes to the original structure are:

Mounts to be added to the spacecraft bulkhead to accommodate the two scanners.

Openings to be made in the solar array and honeycomb substrate to furnish windows for the two scanners.

Considering additions to and subtractions from the weight breakdown of the original spacecraft, the weight of SOMS at separation from the third stage should be approximately 382 pounds. Table 7 is a gross summary of this weight breakdown.

A study of the spacecraft proposed for the Communications Satellite Corporation global system shows that scanners could be added to that structure. Overall weight of this spacecraft with SOMS would be about 75 pounds heavier than the primary configuration, less than, but dangerously close to the maximum spacecraft-apogee motor weight orbitable by a Delta using a TE-364. Although there are alternatives to the use of the HS-303A structure, modification of the latter spacecraft design is feasible without any great redesign and offers a large payload weight margin.

TABLE 7 - Estimated Weight Breakdown, SOMS

Electronics	57 pounds
Harness	5 "
Batteries and solar array	33 "
H_2O_2 control system	13 "
Cameras	24 "
Miscellaneous	8 "
Structure	30 "
Apogee motor case	25 "
Final orbit condition	195 "
H_2O_2 and N_2	22 "
Injected condition	217 "
Total separated weight:	
Injected condition	217 "
Propellant	165 "
Separated condition	382 "

V. GROUND STATIONS

A. Introduction

The Synchronous Operational Meteorological Satellite transmits continuous cloud cover scanner pictures and simultaneously relays medium and slow speed data. In addition, the spacecraft transmits telemetry data and receives and acts on commands sent to it. A single master station will receive the telemetry, command the satellite to maintain its proper synchronous orbit, provide synchronization for the data channels, have the capability to transmit and receive on all thirteen data channels, transmit and receive on the teletype channel, receive the scanner data from the spacecraft, and retransmit the scanner data as a facsimile signal on one of the thirteen data channels. This complete station is called the CDAT; command, data acquisition, and transmit station.

The CDAT station is the only station concerned with servicing the spacecraft, all other stations are concerned only with relaying data and/or obtaining data via the spacecraft. Many types of stations with varying complexity and data capacity can be visualized ; however, two types of data stations will be described, besides the CDAT, illustrating the full range from minimum station to maximum station, (and also minimum cost to maximum cost). In addition, it should be noted that the system data frame structure, shown in Figure 3, could be changed without affecting the spacecraft, to allow reduction in the complexity of the ground station, or to increase the capacity of the system with an attendent increase in complexity.

The ground stations described in this section, for use with the format of Figure 3, are the DA (data acquisition) stations which receive teletype only; the DAT (data acquisition and transmit) stations which receive teletype and receive and transmit on one to thirteen data channels; and the CDAT, the master station with full capability. The DAT station is constructed of a main frame with additional channels accommodated by module plug-in; the other stations are fixed. Figure 18 shows the different station capabilities.

B. DA Station

The block diagram of the DA station is shown in Figure 7. This is the simplest station and uses a standard six foot dish and mount to receive teletype only. A preamp and communications receiver tuned to 1.6936 GHz with a bandwidth of 11 kHz selects the teletype signal only, since the communications transmitter is shifted during the teletype channel time from the 1.695 GHz communications frequency to the 1.6936 GHz teletype frequency and is then frequency modulated by a subcarrier. The subcarrier is phase modulated by five teletype bits for each teletype character at about a 1 kHz rate, therefore the frequency demodulated receiver output is phase demodulated externally into an NRZ signal. During the period when no teletype signal is present, wideband noise will be present at the output of the receiver and will be detected for a squelch signal. The bit detector clock, as well as the teletype modem clock is developed from monostable multivibrators for economy. The five detected bits are shifted into a register and shifted out at teletype rate with a start and stop added. The regenerated teletype start and bit pulses are 13.5 milliseconds long and the stop pulse is 19 milliseconds long, making up the 100 millisecond character rate of a 100 wpm teletype and the equal 100 millisecond frame rate of the communications system. A gate is generated in the last 5 milliseconds of the multivibrator-generated 100-millisecond period, and the next frame is allowed to either begin early or up to 5 milliseconds late depending on detection of the next transmitted frame. In this manner the average frame rate is kept correct while individual frames may vary $\pm 5\%$, (well within acceptable limits).

The output of the shift register with the regenerated code is fed through a power switch to provide a floating output with a mark resistance of less than 130 ohms and a space resistance of greater than 2,600 megohms at 260 volts. A standard teletype printer set for 100 wpm will accept and print the data.

C. DAT Station

The DAT station is the most complex data station. It receives the teletype, receives and transmits on at least one data channel, and can be modularly built up to full thirteen channel capability. In addition, the cloud cover picture can be received directly from the spacecraft in real time if desired. This is optional, however, since the picture will be retransmitted as a facsimile picture on one data channel by the CDAT station, and this reception will be much more economical than the direct equipment (see Figure 6B).

A 30 foot dish with a parametric amplifier is required to receive the higher rate data channels and the scanner channel. A standard receiver with a special phase demodulator and two intermediate frequencies receives the communications and the teletype channels. The teletype channel is processed as described in the DA station. The communications channel is phase demodulated into an NRZ bit stream and fed to a standard bit synchronizer. A squelch is developed in the receiver which disables the bit synchronizer and holds its PLL VCO at midfrequency until the carrier is acquired. After the carrier is acquired, channel sync acquisition is begun. The first 255 bits of each channel are identical channel sync words. Frame sync is denoted by the first channel sync after the teletype channel. Channel sync is a pseudo-noise code generated as a maximal length linear shift register sequence by a register of length eight. This code allows positive synchronization without excessive equipment.

When frame sync is first detected, a channel-predictor and transmit-sequencer are begun. These predict the earliest time to expect a channel, and also identify the channel. The transmit sequencer provides the timing to place the transmitted data in the correct time slot. In addition, the transmit sequencer provides a constant time delay between the received time slot and the corresponding transmit time slot. This fixed delay is manually set into each individual station after launch to account for the different propagation delays for the different stations. This delay correction will have a vernier which should be readjusted daily. An automatic measure of the transmitted channel location will be made by measuring the number of bit periods occurring between the earliest channel time derived from the frame sync and the actual channel sync time. If this exceeds a maximum, an alarm will sound and the operator, by observing a commercial electronic counter display, can readjust the vernier time delay.

Data to be transmitted is connected to a channel input and a switch adjusted to connect the channel to the desired time slot. The channel is then continuously digitized in an A-to-D converter with better than 1% accuracy (7 bits). The conversion is at a 7.7 kHz rate which is fed into a 1024 word buffer. The beginning of memory load is synchronized to the channel transmit slot, therefore 0.1 second must be allowed whenever a channel is switched; however, as long as a channel remains switched in, data transmission can start and stop at will. The memory is unloaded and transmitted in 770 word bursts with the channel sync automatically sent at the beginning. The bursts are sent in the selected time slot by the transmit sequencer which also gates the transmitter on and off. This is repeated at 0.1 second intervals until the channel is switched off.

Data for a desired receiver channel is selected by a front panel switch which connects the channel predictor for the output desired to a 1024 word buffer memory. A mark is generated after the following events have occurred: the channel predictor marks the channel time slot; the receiver denotes acquisition of the carrier; and channel sync is detected. From this point, the incoming bit stream is broken into seven bit words and loaded into a 1024 word buffer. After 64 words are loaded the first time after switching in, the buffer begins unloading at a 7.7 kHz rate. The 64 word reserve allows for jitter in the received data frame rate. When 770 words are loaded, the buffer load stops until the next frame is ready to load the next 770 words. The unloading remains continuous at 7.7 kHz rate. A D-to-A converter on the output converts the 7 bit samples back to analog data.

There are 21 spare bits following the channel sync. The first seven of these bits are used for station call so that a station with a limited number of output channels can recognize an incoming call even though that station happens to be monitoring another channel. The call indication will be panel lights indicating the time slot which the addressed station is to monitor. In addition, panel lights denoting unused channels will be provided. The other 14 spare bits can be used for additional teletype channels or other supervisory duties.

If the station should elect the option of direct scanner picture output, the data are received continuously on a separate communications receiver. The data consist of a burst of video during each spin of the spacecraft plus a sun pulse during the interval between bursts. A relationship between the time of day, the sun pulse, and the edge of the picture exists and provides a method of synchronizing the picture. The synchronization and the video processing are described in detail in a later section. The output picture is processed on an electronic facsimile which digitizes the data and develops a digital sweep to provide better than 3000 element resolution. The final picture is on 70 mm film.

D. CDAT Station

The CDAT station receives the scanner pictures in real time, has full transmit and receive capability for all data channels, and services the spacecraft by reception of telemetry and issuance of commands (See Figure 6A).

The reception and processing of the scanner data are the same as described for the DAT station and are treated in detail in a later section. The handling of the data channels is generally the same as described for the DAT station and will be described in detail later.

The teletype input can be either from a teletype transmitter, teletype terminal, or from a paper tape reader upon which the five level code has been punched. The system stores the five bits of code and transmits them during the teletype time slot as a five bit burst, phase modulating a subcarrier which frequency modulates the transmitter. In addition, the timing signal (derived from the master transmit sequencer) gates on the transmitter and shifts its frequency to 1.6936 GHz for the teletype transmission period.

The servicing of the spacecraft consists of monitoring telemetry of power, temperatures, and equipment status; determining the attitude and spin rate; calculating corrective action required for station keeping, and issuing commands to implement the correction. The details of this function are described in a later section dealing with command and telemetry.

E. Ground Station Subsystems Description

Video Recording and Display

The proposed video recording and display portion of the ground equipment is shown in block diagram form in Figure 19. Major components of this equipment are the composite video separator, the synchronizer, the photofax display unit, and the video recorder. The inputs required to this equipment are the demodulated composite video information from the video receiver and scanner operating mode and scan direction information. The system provides the capability to display the received video information in real time and/or store the data for off line display.

The following is a brief description of the equipment operation. A more detailed analysis of each of the system blocks will be presented later in the text. The composite video which contains scanner video and sun pulses is operated on by the composite video separator. This separator separates the sun pulses from the scanner video. Video information from the composite video separator is connected directly to the photofax display unit, and the sun pulses are connected to the synchronizer. As shown in the block diagram the other inputs to the synchronizer are the outputs from the video-sun angle adjuster and the time of day clock and the scanner mode and scan direction information. The video-sun angle adjuster provides the capability to adjust for the delay between the leading edge of the sun pulse and the photofax line sync pulse that is initially required to present the useful video information on the photofax display. The time of day clock provides the input required to automatically adjust this delay as the sun pulse-to-video delay changes with the time of day. The synchronizer provides line sync, frame sync, deflection clocking, and scan direction information to the photofax display unit.

A more detailed analysis of the system unit blocks follows:

Signal Switching Control: This unit supplies the signal and power switching necessary to provide the capability to (1) display and record real time data, (2) record only, (3) display only, or (4) display recorded data.

Composite Video Separator: The composite video consists of scanner video information which is negative going from zero volts and sun pulses which are positive going from zero volts. The separator will consist of an amplifier followed by a phase splitter which is followed in turn by parallel amplifier-clipper-amplifier chains. A block diagram of this unit is shown as Figure 20.

Synchronizer: The synchronizer is the heart of the video display system. It must supply line sync pulses and deflection clocking to the photofax with an accuracy of one tenth of a resolution element line-to-line error and hold the overall raster horizontal skew to 10 resolution elements or less. It must also provide the frame start or sync pulse to the photofax. The accuracy required of these various timing outputs dictate the need for a highly stable and accurate timing source. Since the satellite spin rate can be expected to vary between 70 and 130 rpm, the synchronizer must also be capable of automatically adjusting the output clock rate in accordance with the satellite spin speed.

Satellite spin rate information must be obtained from the satellite sun sensor output pulse. This sun pulse has a rather noisy nature. The sun sensors used aboard the ATS series have a peak-to-peak jitter of approximately 2 milliradians when installed aboard a satellite spinning at 100 rpm. A more sophisticated sensor now under development for NASA will provide a peak-to-peak jitter of approximately 0.4 milliradian under the same operating conditions. Even with this advanced sun sensor, timing and synchronization pulses having the required accuracy will not be obtainable on a rotation to rotation basis. The proposed approach to the timing and synchronization problem is a modified version of the synchronization system that is under development for use in the ATS-C Image Dissector Camera System. An overall video system error analysis and discussion pertaining to the determination of the required synchronization system parameters are presented later in the text.

Frequency Controller. Figure 21 shows a simplified block diagram of the synchronizer frequency control. In the diagram, f is a frequency source, M is a fixed radix frequency divider, and R is a pulse counter. The philosophy of this approach is to divide the source frequency, f, by a fixed number M during a rotation of the satellite. The number of M cycles in f over this time interval is then given by the number accumulated in R. A subsequent division of f by this number accumulated in R then results in M pulses per satellite rotation. For this relationship to hold exactly, f must be an integer multiple of M. This requirement provides the basis for error sensing and therefore frequency control.

A more complete block diagram of the frequency control portion of the proposed synchronizer is shown in Figure 22. Here the frequency source becomes a voltage controlled crystal oscillator (VCXO) and logic is added for error sensing and for establishing the control voltage for the VCXO. A buffer provides storage of the number accumulated in the R counter, and a second frequency divider and a comparator permit the division of the VCXO frequency by the stored R count so that M pulses per satellite rotation can be generated.

Frequency control is accomplished as follows: The M and R counters are initially cleared by a sun pulse. At the receipt of the next sun pulse the contents of the M counter is sensed to determine if the contents differ from zero by a number of counts in excess of the system error threshold, which is determined primarily by the jitter on the sun pulse. If the error is greater than this system threshold, a unit correction to the frequency is made by applying a pulse to the up-down counter from which the control voltage for the VCXO is derived. The VCXO frequency will be increased by the addition (up count) of this pulse if the M counter indicates a deficiency of VCXO output pulses over the rotation period. Similarly, the frequency of the VCXO will be lowered by the subtraction (down count) of this pulse if the M counter indicates an excess of VCXO output pulses. When a frequency correction is made, the M counter is immediately cleared, the R count is transferred to the buffer, and the R counter is then cleared. This procedure continues at each successive sun pulse until the sensed M count lies within the system error threshold.

As soon as corrections cease to be necessary on each rotation, the system automatically begins an integration process by not clearing the M counter. This counter then acts as an algebraic adder that accumulates the signed sum of the frequency error and/or sun pulse jitter error sampled at each sun pulse time. When the accumulated sum exceeds the system error threshold, a frequency correction is made as described earlier. This technique produces a digital integration of error with a time constant determined by the existing errors. That is, the larger the error, the more quickly corrections take place.

The selection of the radix for the M counter is based on the number of scanner resolution elements which from 2000 lines in 16° is 45,000 elements per satellite rotation. Determination of the VCXO center frequency is influenced by several factors. From the standpoint of logical implementation a relatively low frequency is desirable, but since VCXO's can be pulled only a few tenths of a percent about their center frequency, an extremely high frequency is indicated. The use of the R counter in the frequency control permits the use of a VCXO frequency that also permits the application of digital techniques. Knowing that f and M must be integrally related and having chosen the value of M, the VCXO frequency can be established by selecting a value or range for R. At the lowest satellite spin rate (70 rpm) the VCXO center frequency will be MxR max x 7/6 Hz. Taking R max as 300 yields an f equal to 15.75 MHz. This would then dictate an R min of 161 at a satellite spin rate of 130 rpm. The frequency shift characteristics which the system will exhibit with the designated values of f, R, and M over the expected satellite spin speeds is shown as Figure 23. The maximum VCXO frequency shift is 51.5 kHz. This swing is well within the present state of the art for a VCXO of the required stability (this stability requirement will be discussed later).

Phasing and Control. Although the frequency control portion of the video display equipment generates a master clock rate which is M times the satellite spin speed, no attempt is made there to correlate this clock output with the scanner video information. It is then the function of the phasing and control circuits to supply the photofax frame sync, line sync, deflection clock, and scan direction information in the proper timing relation with the useful video information. A block diagram of this portion of the synchronizer is shown as Figure 24. The input requirements to this unit are the M ppr clock output, the time of day clock output, the sun pulse, the scanner mode and direction information, and the output from the video-sun angle delay adjust.

The system operates as follows. The M ppr clock input is connected in parallel to the X20 frequency multiplier and the ÷ M counter. This clock input is frequency multiplied in the frequency multiplier to yield a clocking pulse rate of 20 M ppr. The ÷ M counter is initially reset when the sun pulse is manually enabled through the sun pulse gate. This reset should be initiated only after the frequency controller has been set to the tracking mode. Once the ÷ M counter has been reset, it provides simulated sun pulses as long as the frequency controller remains locked. The 20 M ppr clock frequency is connected directly to a delay counter which is reset to a predetermined count at the receipt of each simulated sun pulse (SSP) once the frame start gate has been enabled. The count that is initially set into the delay counter is that delay which yields an output pulse from the delay counter just prior to the receipt of useful scanner video. This delay is set into the time of day correction counter manually through the use of the delay adjust.

Once the proper initial count has been set into the time of day correction counter, the time of day clock continually updates this delay to compensate for the change in delay between the sun pulse and the usable video information. The time of day clock and delay adjust circuits will be discussed later in the text. As mentioned previously, the contents of the time of day correction counter are parallel shifted into the delay counter at the occurrence of every SSP. The output pulse from the delay counter is connected to the photofax line sync pulse shaper, and also connected in parallel with the 20 M ppr clock to the coincidence control. This control enables the 20 M clock output through to the divide by 20 counter when the delay counter output is received. In this manner the M ppr deflection clock output to the photofax is properly phased for display of the video information as time progresses with an accuracy of at least 1/20 of a resolution element. The frame start and direction logic provides the frame start enable pulse to the frame start gate and to the photofax frame sync pulse shaper. This logic block also supplies direction information to the photofax so that the printout can be identified as either a forward or backward scanned picture.

Time of Day Clock and Sun-Video Angle Delay Adjust: Because the SOMS is earth synchronous and because the synchronization system must use the sun pulse as a frequency or clock source, the delay between the receipt of the sun pulse and the usable video information (a function of the angle between the earth-sun line and the earth-satellite line) changes with the time of day, and unless corrected for, causes a horizontal skew in the video display raster. The earth rotates about its axis at the rate of 15 seconds of arc rotation per second of time. The function of the time of day clock, in conjunction with the synchronizer, is to compensate for this rotational error in the display raster in as smooth a manner as is feasibly possible. The scanner resolution element size is 8×10^{-3} degrees of arc. This is the angular distance that the satellite moves during the period of each M ppr clock cycle. If the time of day clock were set up to give an output at 8×10^{-3} degree of arc increments of the earth's rotation, the picture skew due to time of day rotational changes could be eliminated in the manner described in the previous section, but the line-to-line error could only be held to $\pm$ one picture element. In order to reduce the possible line-to-line error the M ppr clock input to the phasing and control is frequency multiplied to 20 M so that corrections can be made to an accuracy of 1/20 of a resolution element. The clock output for this system is required at earth rotation increments of 4×10^{-4} degrees of arc. This defines a time of day clock output at 9.6 Hz. This clock will employ an oven oscillator of a few hundred kHz with a stability of 2 parts in 10^8 from which the 9.6 Hz can be derived.

The sun-video angle delay adjust simply provides a method by which the time of day correction counter in the synchronizer can be set to that number which gives the proper sun-video delay at the initial turn on of the scanner or display equipment. Figure 25 shows a block diagram of the unit. The only input required to the adjuster is a 100 kHz clock. This input should be available from the time of day clock oscillator. A series of manually actuated one shots will then be used to enable this clock output to up count or down count the time of day counter to the desired initial number.

Video Synchronizer Parameter Determination

At this time "state of the art" satellite camera ground synchronization and display systems are capable of laying down successive lines on the display raster with a horizontal placement accuracy of at least one half of one resolution element and of holding the total raster horizontal skew to 1% or less of the picture width. It will therefore be the objective of this system to provide a line-to-line error of 30% of one resolution element or less and a horizontal skew of no more than 1%.

The following is a list of the factors which could cause synchronization or presentation errors:

- Synchronizer VCXO stability
- Satellite spin rate stability
- Sun pulse jitter
- Synchronizer VCXO reference voltage stability
- Time of day correction accuracy
- Satellite attitude control
- Satellite position
- Photofax display accuracy

Each of the error contributing factors listed above will now be examined:

Synchronizer VCXO Stability: In order that the VCXO contributes no significant error on a line-to-line basis, the oscillator stability requirement will be set as that which yields no more than .01 of one resolution element error. Since there are 45,000 resolution elements per satellite spin, that would require

$$\begin{aligned} \text{Stability} &= 1/100 \text{ in } 45{,}000 \\ &= 1 \text{ in } 4.5 \times 10^6 \\ &\cong 2 \text{ in } 10^7 \end{aligned}$$

This stability requirement is well within the "state of the art" for oven enclosed crystal controlled oscillators.

Satellite Spin Rate Stability: The Syncom or ATS type satellites have exhibited a steady state spin decay rate of 1 rpm in 100 over a period in excess of one year. As a worst case condition the spin decay rate will be taken as 1 rpm in 100 over one year. That is

$$\begin{aligned} \text{decay rate} &= 1 \text{ in } 100 \times 365 \times 24 \times 60 \\ &= 1 \text{ in } 5.26 \times 10^7 \\ &\cong 2 \text{ in } 10^8 \end{aligned}$$

This decay rate would yield a line to line error of 0.001 resolution element.

Sun Pulse Jitter: For this case, sun pulse jitter is acted upon by the digital integration of the synchronizer error sensing unit. On a line-to-line basis the error is therefore a function of the system noise threshold and also the amplitude of the system unit step correction. In order to determine the optimum relationship between peak sun pulse jitter, noise threshold, and correction step amplitude, the operation of the frequency control section of the synchronizer being developed for the ATS-C Image Dissector Camera System was simulated on a digital computer. Computer runs were conducted with various noise to threshold relationships. From the results of these computer simulations it was determined that the optimum relationship was a synchronizer noise threshold of 1.2 times the peak noise amplitude for a gaussian noise distribution. During the computer runs the correction step was set at 0.01 of the noise threshold. For this system then, the noise threshold in the tracking mode will be set at five resolution elements (sun pulse jitter p-p is expected to be four resolution elements) and the unit correction step as 0.05 resolution element. During the acquisition period the step correction will be increased to one resolution element to reduce the required lock up time. Once the system is operating in the tracking mode, the worst case line-to-line error due to sun pulse jitter will be one unit step correction or 0.05 resolution element. The error limits will be $\pm$ 5 resolution elements or 0.5% of the total picture width.

Synchronizer VCXO Reference Voltage Stability: A unit step correction of 0.05 resolution element is a VCXO frequency change of 10.3 Hz (at a spacecraft spin rate of 100 rpm). Since the VCXO will have a frequency swing of $\pm$ 51.5 kHz, the D/A converter must be capable of generating 10,000 steps. If these steps are held to an accuracy of 0.2 step amplitude (0.01 resolution element) the D/A converter-reference voltage regulator combination must be made almost noise free. This task is difficult but not impossible. (For a 20 volt reference and a voltage driven resistance adder D/A, the individual steps would have to be two millivolts $\pm$ 0.4 millivolt.)

Time of Day Correction Accuracy: As stated previously in the text, the time of day clock-synchronizer combination will be capable of correcting the picture skew with an accuracy of 0.05 resolution element on a line-to-line basis. This capability is a function of the X20 frequency multiplier in the phasing and control unit. On a long time basis, however, the picture skew is a function of the long time stability of the time of day clock master oscillator. In order that the picture skew not be more than two resolution elements per frame, the oscillator stability would have to be

$$\text{Stability} = 2 \text{ in } 2000 \times 45000$$
$$\cong 2 \text{ in } 10^8$$

An oscillator of this stability is easily obtainable.

Satellite Attitude Control: One of the stipulations of this program is that the satellite attitude control system hold the scanner system errors due to undesirable satellite motion (nutation mainly) to .15 resolution element or less on a line-to-line basis.

Satellite Position: On a short time basis, the satellite has been worst cased to have a maximum longitudinal deviation of $\pm$.5 degrees over a 24 hour period. The nature of this motion would be a figure 8 over a 24 hour period. The worst case condition would then be a satellite position error of .5° in 3 hours or an average error rate of 200 arc seconds or 7 resolution elements per frame (20 minutes).

Photofax Display Accuracy: The photofax display unit that is being proposed for use here has an overall linearity of .5% and is capable of laying down successive lines on the display raster with a line-to-line accuracy of .1 resolution element.

Table 8 lists the system error contributing factors and also the total system peak and rms errors that can be expected. It can be seen that the proposed system more than meets the required accuracy on an overall systems rms error basis.

TABLE 8 - Video System Error Producing Factors

	Error Factor	line-to-line (in resolution ele.)	per frame (in resolution ele.)
1.	Synchronizer VCXO stability	0.01	---
2.	Satellite spin rate stability	0.001	---
3.	Sun Pulse Jitter*	0.05	± 5
4.	Sync VCXO ref. voltage stab.	0.01	---
5.	Time of day correction accur.	0.05	2
6.	Satellite Attitude	0.15	---
7.	Satellite Position	0.0035	7
8.	Photofax Display	0.10	10
Total System Error			
	P-P	0.3745	29
	rms	0.194	15.9

*Resultant error from digital integration

Communications System Detailed Description CDAT and DAT

The communications systems in the CDAT and the DAT stations are almost identical except the DAT may not have all the channels installed. The operations are similar, however, and the tasks and descriptions to follow apply to both types of stations.

The tasks to be performed are: synchronization to frame sync (CDAT synchronizes to a master clock); location and buffering out of the different received channels; and sampling and transmitting the incoming channels in the proper time slot. In addition, supervisory codes may be inserted into the spare word of each channel and these detected continuously even if the channel is not deliberately monitored.

The system description which follows refers to the block diagram of Figure 26.

The raw data from the receiver output enters the commercial bit synchronizer as an NRZ signal. The output of the bit synchronizer is the reconstituted bit stream and the bit clock. In addition, the bit synchronizer receives a squelch signal from the receiver when no carrier is present. The bit clock is held at center until the squelch disappears denoting carrier lock on.

After system turn on, or an out of sync condition, frame sync must first be found. This is accomplished by receiving a squelch off signal from the teletype channel for about three milliseconds which indicates that the teletype channel has been received and that the next channel sync is frame sync. (The same 255 bit code is used for frame and channel sync.) Since the teletype channel is out of band of the communications channel, the bit sync will not be enabled until approximately 50 bits after the start of frame sync. At that time, carrier acquisition will occur and the bit synchronizer will be enabled by the receiver squelch. The first few bits out of the bit synchronizer will be in error as it acquires bit sync; however, the sync code is well protected and these errors will not hinder acquisition of sync or contribute to false sync.

The scheme to find sync is as follows. The first eight bits of the sequence to be examined are loaded into an eight bit register by the bit clock. Then the next eight bits are loaded into another register while the first register is caused to recirculate by the bit clock through logic identical to the initial code generator. When the second register is loaded it also regenerates through identical logic, and the next eight bits are loaded into a third register. This continues until all seven registers of the sync detector have been loaded, after which the first register is interrupted and loaded with the following eight bits and the process is then repeated. This loading is accomplished by the sync sequencer and is the first step toward sync detection. The second step in sync detection is the comparison of the contents of all seven registers to each other after each load cycle. When any five exactly agree, the sync word has been detected. This can be shown by considering the method of code generation.* The code generator is an 8 bit shift register in which a fixed word is loaded to begin the sequence. The contents are then observed and fed back through the logic circuit to control the next value of the first stage of the register. All other stages are shifted to the value of the previous stage. The output is taken from the last stage. This generates a sequence that repeats every 255 bits. Now any possible consecutive group of 8 bits of the 255 bit sequence is one state of the generator shift register and since all succeeding states are determined by the feedback, selecting any eight bit sequence of the code, loading it in a register, and then allowing it to recirculate through the logic will generate the code from that point on. In our detector, if the first register has a correct eight bit sequence it will generate the next 8 bits by the time the second register has the next 8 bits loaded into it and so on. When 5 out of 7 agree, the sync word is detected with a probability of 2 parts in 10^{11} of false sync.

The third step in sync detection is to detect the last bit of the code in order to mark the beginning of data. This is done by looking for the known last eight bits of the code in one of the registers that were in agreement in the 5 out of 7.

The registers are not dumped after the 5 out of 7 detection, but are allowed to recirculate by the bit clock. In this manner, any errors in the last eight bits of the incoming code do not affect sync. This of course assumes no loss of bit sync after the 5 out of 7 detection; however, for this system, with a tight bit-clock-loop, this will be the case. The sync thus detected is a very positive sync which can ignore large bursts of errors and is immune from false sync generation.

* See Digital Communications; Golomb, et al; Prentice Hall; 1964 and Advances in Communication Systems; Balakrishnan et al; Academic Press, 1965

There is one exception, however, and a special detector is used to eliminate this problem. The problem is that if constant zeros should be loaded in (a slight possibility when searching for sync), the zeros would continue to regenerate as zeros, and after 40 were loaded, the registers would agree without being in the generation sequence. Therefore, the all zero state will be detected and will disable sync detection since it is always an illegal state in the sync word.

The sync detector contains the seven eight bit registers, the five out of seven agreement detector, and the exclusive or feed back gates for each register as well as input gates and the end of sequence detector. The sync sequencer contains the counters to load the eight bit groups cyclically, and the enable gates. The channel sync is detected in exactly the same manner, the only difference being the location relative to the teletype channel.

Coincident with the last bit of frame sync detection, the channel predictor and transmit sequencer is started. The exact time of each received channel is uncertain since each will jitter slightly due to the tolerance in propagation delay compensation. Each station will be attempting to synchronize to the master station frame sync, however, so the timing errors are not cumulative and definite windows may be framed about expected times relative to the frame sync. The sync predictor does this, and provides identification signals that can be switched to direct the desired information to the selected output. Acting in conjunction with the channel predictor is a transmit sequencer which generates exact times relative to the frame sync in order to control channel transmission. This sequence is delayed from the frame sync by a fixed delay manually inserted at each station to accommodate the propagation delay. It is made up of a coarse selector plus a vernier which adjusts to the nearest bit period. In addition the channel predictor fixes the earliest time any active transmitting channel of the station should be received. The number of bit periods between this and actual sync detection are counted and if out of tolerance ($\pm$ 20 + 255) an alarm is sounded so the operator may readjust the transmit time delay.

The incoming data is handled by the data sequencer. This is a seven bit counter which upon a mark pulse begins loading seven bit groups into selected buffer memories (after counting out the three spare words) and which counts 770 loads and then resets until the next mark pulse.

A typical channel will be received as follows: After the mark is received, the first three groups of seven bits are shifted through the data register, and the call detectors are enabled to detect whatever supervisory information is chosen to be included in these spare words. The outputs of the detectors go to front panel lights and the detection is such that the lights can be lighted even though the particular channel is not being monitored by the station.

After the spare words are shifted through, the remaining data are loaded into the buffer memory chosen by the front panel channel selector switch. The loading is accomplished by bit clock shifting 7 bits at a time into the register and loading each 7 bits in parallel into the buffer.

The buffer size necessary is 770 words plus twice the possible number of words transmitted during the channel time uncertainty. The channel uncertainty words are a maximum of 12; however, since standard buffers come in 512 and 1024 word sizes, the 1024 word size was chosen. The buffer is unloaded at a constant rate of 7.7 kHz, and this is synchronized so that load and unload pulses are always spaced at least one microsecond apart (memory cycle time). The 7 bit words unloaded from the buffer are presented to a D to A converter which reconstructs the analog data for this channel. Of course, digital information could have been transmitted, in which case the output would come directly from the buffer utilizing the unload pulses for transfer.

The above description shows how one channel is handled; however, the synchronization is present for all channels once it is obtained for one channel. Therefore, a station may have only one output buffer and D to A converter which can be switched from channel to channel, or can expand at any time by simple plug-in of the buffer-converter-switch module.

The other major job of the system is collecting the incoming data and transmitting it in the proper time slot. The incoming data for each channel are digitized at a constant 7.7 kHz rate with the synchronized ground clock. Each channel is loaded into its 1024 word buffer as 7 bit words, 7 bits per sample. The beginning of the sampling of a channel is synchronized to the selected time slot in which it is to be transmitted. Therefore up to 0.1 second is necessary before beginning transmission whenever data are changed from one time slot to another or when data are first initiated. Once connected, however, data are accepted continuously. This synchronization allows the buffer size to be less than two frames capacity and a 1024 word memory is used because the size is standard and it is interchangeable with the receive buffers.

The output of the buffer is parallel transferred to a 7 bit register and shifted out at the transmit bit rate of 798 kbps for 770 words during the transmit time slot. The transmit sequencer and the front panel switch control the shift out and transmit functions. The sequencer triggers the sync generator which transmits one 255 bit cycle plus the three 7 bit spare words before the 770 word burst is generated. The transmit sequencer also gates the transmitter on at the beginning of the sync word and off at the end of the data burst.

One buffer and an A to D converter is necessary for each channel to be transmitted. However, just as in the receive case, a station may use one transmit module and switch it from time slot to time slot, or increase its capability by installing more buffer-converter-switch modules, as needed.

The teletype transmission, which is normally reserved for the CDAT station, but could be originated by a DAT station if desired, will now be described. The teletype time slot is determined by the transmit sequencer, which in the CDAT station is synchronized to the master clock. The start of teletype transmission is a character behind the input to allow a full 5 bit code character to be assembled and sent as a 5 bit burst during the teletype time slot. The input can be a standard 100 wpm teletype line or a paper tape coded in teletype 5 level code which is read by the system paper tape reader. At the same time as the transmit sequencer begins the data readout, the tramitter is gated on to the 7234.88 MHz frequency and the data connected to the teletype modulator, where the five bits are transmitted for the one teletype character. This is repeated at 0.1 second intervals.

Telemetry and Command

The primary function of the telemetry and command subsystem is to control and monitor from the ground the performance of the spacecraft. Complete capability of monitoring and controlling the spacecraft is provided only at the master terminal, CDAT.

During the initial transfer orbits, telemetry and command capability will be provided by a VHF link from the tracking and data system network. As the need for a VHF telemetry link disappears after approximately 8 days (or after the predetermined station is reached), no VHF telemetry capability will be provided at the SOMS ground terminal, thereby eliminating the cost of a VHF installation that would include a separate antenna, pedestal, foundation, a transmitter, power supplies, command encoders, and associated test equipment. Telemetry and command capability will be provided by using the higher microwave frequencies which are close to the communications frequencies.

Figure 27 is a block diagram of the telemetry and command loop. Major components are the command panel, telemetry panel, synchronous controller (all located in the operations console), receiver and transmitter.

Command: A command to the spacecraft is accomplished in three discrete steps; enable, command, and execute.

Execution of a command starts by transmitting, at a frequency of 7225 MHz, an enable tone which applies power to the command resistor and associated circuitry in the spacecraft. A command pulse train transmitted and confirmed from the telemetry ensures that the command has entered the spacecraft register correctly. After confirmation, the execute signal is sent to the spacecraft, which causes the stored command to be decoded and executed. After the command has been executed, other commands can be sent, or the system in the spacecraft can be returned to a passive state.

Command Panel: The command panel provides the capability to execute the command sequence previously described. The panel, located in the Operation Control Console contains all the indicators, switches, and displays to execute the commands. Display lights on the panel indicate the command stored, the operating sequence, verification that the proper command has been received at the spacecraft, and the status of the command sequence. Switches on the panel allow selection of the desired command code count, and of any of the five modes of the execute signal.

The normal execute mode is the pulsed mode, in which an execute tone burst is sent each time the execute switch is depressed. The controller mode (manual) is used to fire the control jets in synchronism with the satellite spin rate; in this mode, an execute signal at a selected angle of spacecraft rotation and for a controlled duration, is sent on each revolution by pulses generated from the controller. The controller mode (automatic) performs a function identical to that of the manual mode, except that the desired number of execute signal repeats can be preset from a counter. When the total number of verifications equals the number of pulses present in the counter, the execute signal is gated off and no other signals can be transmitted. A continous mode allows the execute signal to be sent as long as the execute switch is depressed. The fifth mode is timed mode, used to send execute signal for a predetermined duration, using the counter as previously described.

A key switch-lock combination prevents any of the three discrete command steps from leaving the command panel unless the key is inserted and the switch actuated.

Telemetry: The telemetry is used to monitor on the ground various spacecraft parameters such as temperature, attitude, spacecraft-control gas pressure, stored commands, and various voltages throughout the spacecraft. The parameters are encoded and modulated on the microwave beacon carrier operating at a frequency of 1691 MHz.

The telemetry signal is received on the ground through the parabolic communications antenna into a crystal-controlled double-conversion superheterodyne receiver with a phase-locked loop to improve signal detection.

Telemetry Panel: The detected signal from the telemetry receiver is received at the telemetry panel for further filtering and processing into information channels. The information channels contain the data needed for day-to-day operation of the communications system and for monitoring spacecraft parameters on the ground.

The operational data are filtered and detected in separate circuitry before being received at the command panel, the recorder, or the controller. The data containing the monitored spacecraft parameters, along with the command enable and the command signal, are processed through a filter centered at 14.5 kHz and having a bandwidth of 4.2 kHz at the 1-db points. The filtered signal is received at the discriminator where the various information channels are reconstructed. The output of the discriminator is then recorded as permanent data of the spacecraft parameters, or is used to generate gates, channel synchronization pulses, and channel identification codes for the day-to-day operation of the system.

Controller: One problem encountered in station-keeping for a synchronous satellite is to determine the spacecraft attitude and spin rate, so that the control subsystem can be activated when the control jets are in position to move the satellite in the proper direction. The purpose of the synchronous controller is to determine this position within the required accuracy, and to cause the synchronized jet pulses to fire at any angle of spacecraft rotation for a controllable length of time.

The major components of the controller are two sun-pulse trackers, a frequency-interval counter, an oscilloscope, and the digital controller.

The sun-pulse trackers generate pulses for each solar pulse received, so that the leading edges of the reconstructed pulses are coincident with the maximum amplitude of the actual sun pulse. The duration of the reconstructed pulses is 1 millisecond. Reconstructed pulses from one sensor are sent to the frequency-interval counter where the satellite spin rate is determined by counting pulses over a period of time. The attitude of the spacecraft is determined by observing on the oscilloscope the time delay between reconstructed pulse 1 and reconstructed pulse 2.

In addition to reconstructing the received sun pulses, the sun-pulse trackers divide the rotation period into 32 equal increments, 11.25 degrees wide, which are sent in a digital form to the digital controller for programming the jet-activate time, relative to the position of the jet and the sun line. The digital controller then automatically generates the synchronous jet-pulse execute signal according to the spin period determined from the sun pulse trackers. The start time and the jet-pulse duration controls are manually adjusted according to information on the spacecraft's attitude and spin period.

A coarse jet-start angle control allows selection of the jet start angle relative to the sunline to the nearest 11.25 degrees; a fine start angle control allows an incremental adjustment between 0 and 11.25 degrees. A jet-pulse duration control allows adjustment of the firing period of the selected jet. The output from the digital controller is a synchronous jet-pulse execute signal sent to the command panel for use at the desired time.

Receiving Subsystem

The CDAT receiving subsystem includes two groups of receivers, the data receivers for communications, scanner and telemetry; and an autotrack-telemetry receiver which provides the azimuth and elevation error signals generated from the beacon-carrier signal and the telemetry panel signals.

The three receivers are preceded by an uncooled parametric amplifier inside the antenna receive/feed structure, which is capable of simultaneous reception of three modulated RF carriers from the satellite. The receiving frequencies are 1697 MHz for the scanner data, 1695 for the operational communications traffic (1693.6 MHz for TTY), and 1691 for the beacon signal, which provides the telemetry output as well as the autotrack reference. Mounting the parametric amplifier with the feed structure will provide an assembly optimized for stable low-noise performance.

The DAT station is the same except there is no autotrack or telemetry. The antenna is manually aimed. The DA station uses a 6' dish manually aimed and a single narrow band communications receiver.

System Noise Temperature: For this study, overall system noise temperature at the communications receiver, frequency-referenced to the input of the paramp, theoretically will not exceed 150°K with the antenna pointing at an elevation angle of 7.5 degrees on a clear day (assuming optimum operation of the uncooled parametric amplifier and minimum cable losses).

Communications Receiver: The communications receiver is a phase-locked dual-conversion crystal-controlled system capable of optimizing the performance in the reception and demodulation of a full $\pm 90^{\circ}$ PSK signal. Operation of this receiver is conventional. A down-converter translates the 1697 MHz RF input signals down to I.F. frequency. A bandpass filter with adjustable characteristics initially sets the bandwidth of the respective systems. A coherent phase-lock demodulator and detector recovers the pulse-code-modulated signal.

The reconstructed pulse-code-modulated signal is baseband amplified and sent to the bit synchronizer. A squelch signal is developed when loss of carrier in the 1.695 GHz band occurs. This signal is used to maintain the bit synchronizer PLL VCO near the bit rate until the next carrier has been acquired.

Transmitting Subsystem

The transmitting subsystem consists of the components, excluding the antenna, necessary to establish the RF link between the ground and the spacecraft at an operational frequency of 7.23348 GHz communications and 7.225 GHz for spacecraft commands.

The 7.225 GHz command transmitter is used only when commanding of the spacecraft is necessary by the CDAT station. The 7.23348 GHz communications transmitter of the CDAT station transmits the frame sync word each frame plus the teletype word. The teletype work is transmitted by shifting the 7.23348 GHz center frequency to 7.23488 GHz for the period of the teletype.

Operation of this subsystem is conventional. A voltage-controlled crystal oscillator (VCXO) operating at approximately 70 MHz is the basic frequency generator of the system. Using a crystal oven to stabilize the temperature, an overall frequency stability of 1 part in 10^8 should be easily achieved.

The balanced biphase modulator will be modulated by the digital-coded input data. This modulation scheme offers the advantage of high system efficienty, and results in a double-sideband suppressed-carrier signal being sent to the satellite.

The output from the klystron driver amplifier will be conservatively rated to provide sufficient drive to the power amplifier under any condition. Output frequency of the drive amplifier will be the operational frequency in the 7200-MHz region. One stage of up-conversion is used to reach this frequency instead of using the in-line frequency-multiplication scheme.

The power amplifier will use a klystron as the high-power generator to ensure an output conservatively rated at 5 kw at the output of the waveguide flange. The klystron amplifier offers the advantages of optimized performance, size, and weight. If required, the output could be made continuously adjustable over a 10-db range below the maximum output.

The power amplifier will be mounted on the antenna structure near the elevation axis to minimize the waveguide necessary between the output and input of the transmit feed. Amplifier controls will be located on the operational console, along with fault indicators for indicating faults occurring within the unit. All other components of the transmitting subsystem will be mounted, except as noted, in or near the operations shelter. The output waveguide components will be pressurized to minimize the danger of arcing due to the high level of RF power. The pressurization equipment will be mounted at the base of the antenna pedestal along with gauges to register waveguide pressure.

The heat exchanger will be used to dissipate the heat generated by the klystron power amplifier. The liquid-to-air heat exchanger will ensure a maximum inlet coolant temperature of 66°C to the klystron amplifier, water load, and any liquid-cooled waveguide components. A liquid-cooled dummy load will be provided for subsystem testing. Provisions willbe made to connect the dummy load to the power-amplifier output by controls on the operational console. Liquid coolant temperatures at the inlet and outlet, and coolant flow rates to the load will also be monitored at the console.

Antenna Subsystem

The antenna subsystem is a parabolic reflector and feed system supported and oriented by an azimuth - elevation (az - el) mount. Of the two types of feed systems considered, prime focal and Cassegrain, the Cassegrain feed was selected for a number of reasons: The composite feed system located at the vertex of the reflector can be integrally assembled as part of the transmitter and receiver front-end components, minimizing problems associated with the transmission of high RF power levels and with waveguide runs, thereby providing higher efficiencies for both transmission and reception. This configuration also has better accessibility for maintenance, component interchange, component adjustment, and feed installation.

Reflectors: The primary reflector is a 30-foot paraboloid assembled from solid aluminum panels. Positive mechanical connections provide electrical bonding between each panel, and between the panels and support structure. Major truss sections compatible with the number of solid aluminum panels used will support the panel structure.

The f/d ratio generally used for this size reflector is approximately 0.4, giving a system focal length of 12.0 feet.

The subreflector will be a 6-foot one-piece hyperboloid surface supported at the focal point of the system by a quadrapod structure of tubular spars. The quadrapod spars will be designed and attached through the reflector skin to a major truss member to limit any angular deflection of the subreflector to less than 0.2 milliradian and any linear deflection to less than 0.9 inch. The subreflector, at focal point, will be located so that its center lies on one axis of the primary reflector parallel to the corresponding primary reflector axis within one milliradian. Deviation of the subreflector surface from a true hyperbolic curve should not exceed $\pm$ 0.031 inch, and will be measured in the same manner used for the primary reflector.

Deviation of the primary reflector surface from the true parabolic contour should not exceed $\pm$0.080 inch. The contour is measured and set at a 30-degree elevation angle and checked at the zenith and horizon positions to determine if the surface is within tolerance throughout the range of elevation rotation. To minimize heat absorption and prevent a temperature rise creating differential temperature problems, the assembled panel surfaces are painted with highly diffusive reflective white paint to yield a surface with low solar absorptivity and high emissivity in the infrared region of the spectrum.

Antenna Feeds: The contribution from the antenna subsystem must be mimimized in order to keep the system at a practical noise temperature. This requires an RF feed system capable of maximum illumination of the aperture and a minimum of spill-over around the Cassegrain subreflector.

The transmitting antenna on the spacecraft is polarized vertical linear (parallel to the spin axis) and the receiving antennas will be polarized horizontal linear (perpendicular to the spin axis). The feed system of the ground-antenna subsystem should therefore be able to transmit a circular polarized and receive a linear polarized wave front.

Among acceptable techniques available to meet the requirements of the ground-terminal feed system is an array using dielectric rods as the elements; four of these are located at the corners of a square. A transmit element located in the center of the array allows precise beam-axis alignment, with maximum cross polarization alignment with respect to the received signal.

The design of the transmit feed element, which allows transmission of a circular polarized signal in the 7-GHz band, provides sufficient illumination of the reflector for a theoretical peak antenna gain of 54 db. At the 3-db points the RF beam would be 0.3 degree wide, and 80 percent of the RF energy would theoretically be within the 0.185-degree points.

The four elements used in the receive feed, which are sensitive to linear polarization as transmitted from the spacecraft, are all to be designed to be excited in phase for receiving a linear polarized signal in the 1.7 GHz frequency spectrum. With the feeds precisely aligned and excited, a theoretical peak antenna gain of 41.55 db can be obtained at the 1.7 GHz frequency. A simple comparator sums the output from the four elements into a single received signal.

Polarization Plane Adjustment: The technique used for the transmit and receive feed provides a simple approach to rotating the plane of polarization for the operations console. Alignment of the feed polarization with the incident polarization (which is important to optimize the reception of the signal from the spacecraft) is accomplished by mechanically rotating a half-wave polarized section mounted in-line with each feed element. The adjustment can be calibrated so that the readout at the console will be accurate to a maximum of 1 degree. The advantage of this technique of polarization adjustment is that polarization can be tracked continuously without losing polarization sensing at one limit.

Antenna Tracking and Positioning: The problem of tracking an almost stationary spacecraft and of positioning the antenna is not critical or acute. The cheapest and simplest solution is to manually position and track the spacecraft by means of signal-level indications derived from the receiver AGC voltage. This method will be used for all but the CDAT stations.

For the CDAT stations, a simple autotrack capability will be provided for positioning and holding the antenna to within $\pm$ 0.1 degree of the spacecraft. A three channel autotrack system will provide the required pointing accuracy at the lowest possible cost.

VI. LAUNCH VEHICLE AND APOGEE MOTOR DESCRIPTION AND ANALYSIS

A. Launch Vehicle

The launch vehicle chosen is the thrust augmented Improved Delta vehicle, model DSV-3E. The first stage consists of a Thor booster (DM-21) with three Thiokol TX-33-52 solid propellant rocket motors equally spaced about its periphery. The Thor has an overall length of 60.5 feet and a maximum diameter of 8 feet. The Thor utilizes one main engine and two vernier engines, each of which is gimballed. The vernier engines are used for roll control during powered flight and final attitude control for a short period after main engine cut-off. Liquid oxygen and RP-1 are used for propellants and a nominal thrust of 170,000 pounds is delivered by the main engine at sea level. The two vernier engines deliver 1000 pounds of thrust each.

The second stage vehicle consists of the Aerojet General Corporation AJ 10-118 E pressure-fed liquid propellant propulsion system and the guidance compartment structure. This stage is 13.2 feet long with a maximum diameter of 5 feet. The AJ 10-118 E liquid propulsion system uses the hypergolic propellants, inhibited red fuming nitric acid and unsymmetrical dimethyl hydrazine. This stage develops a nominal thrust of 7750 pounds. The thrust chamber assembly is gimbaled for pitch and yaw control during powered flight. Roll control during powered and coast flight, pitch and yaw control for coast flight, and retro capability before third stage ignition are achieved by a cold gas system mounted on the second stage.

The third stage propulsion system to be used for the Comsat Corp. HS-303A consists of the United Technology Center FW-4D solid propellant motor. This motor is 19.6 inches in diameter and has an overall length of 58.4 inches. The loaded motor has a total weight of 660.5 pounds and a burnout weight of 52 pounds. It develops a nominal thrust of 5350 pounds for a period of 32.1 seconds at 0 rpm or 5620 pounds for 30.5 seconds at 200 rpm. Stabilization during motor burn is accomplished by spinning the motor-payload combination prior to 2-3 separation and third stage ignition.

The vehicle described above has the capability of placing a 360 pound spacecraft into a transfer orbit with apogee at the synchronous altitude.

B. Apogee Motor

The fourth stage of the overall vehicle consists of the payload and the attached apogee kick motor. The motor being used for the Comsat Corp. HS-303A satellite was analyzed to determine its payload limitations. This motor is the \erojet-General Corporation Pathfinder solid propellant motor. Table 9 presents the performance characteristics of this motor.

TABLE 9

Pathfinder Motor Performance Data

Total Weight	192.7 lb
Propellant Weight	165.0 lb
Burn Time	19.5 sec
Total Impulse	48,200 lb-sec
Specific Impulse	289 lb-sec/lb

Figure 28 presents the velocity increment capability of the Pathfinder motor as a function of total initial spacecraft weight.

In placing a spacecraft into a transfer ellipse having an apogee near the synchronous altitude, the first two stages of the launch vehicle are used to place the spacecraft-third stage combination into a low altitude circular orbit (100-200 n. miles). The third stage is fired when the spacecraft-third stage combination crosses the equator, thus injecting the spacecraft into a transfer ellipse, the apogee altitude of which is near the synchronous altitude. The maximum circular orbit capability of the first two stages of the DSV-3E Delta vehicle is 184 n. miles, i.e., this is the maximum circular orbit altitude at which the third stage-payload combination can be injected. Looking at Figure 29 one sees that for a perigee altitude of 184 n. miles there corresponds an apogee altitude of 1250 n. miles above the synchronous altitude and an apogee kick motor velocity increment requirement of 5815 feet/second. Using a velocity increment of 5815 feet/second, one finds from Figure 28 that the maximum payload that can be adequately handled by the Pathfinder motor is 355 pounds. This means that if a spacecraft having a total initial weight greater than 355 pounds is to be injected into a synchronous orbit, one must use either a higher performance launch vehicle, or a higher performance apogee motor. It seems that the former alternative would be a better route to follow as a higher performance apogee motor would probably cause a corresponding increase in vehicle weight and possibly necessitate the use of a higher performance launch vehicle.

If 355 pounds is an inadequate spacecraft weight, a 450 pound spacecraft in a transfer orbit to the synchronous altitude is feasible by using the thrust augmented Improved Delta vehicle with the Thiokol TE-364 solid propellant motor as third stage propulsion. The apogee motor in question could certainly be used if the TE-364 third stage were utilized since the mission could then be achieved by allowing the launch vehicle to remove part of the transfer orbit inclination. The removal of the inclination would be achieved by performing a pitch and yaw maneuver with the second stage after second stage cut-off, but prior to third stage separation. This maneuvering is similar to that used in the launching of Syncom III. A slight payload penalty would be paid by such maneuvering, but the remaining capability would still be more than adequate to achieve a successful mission and allow for spacecraft growth.

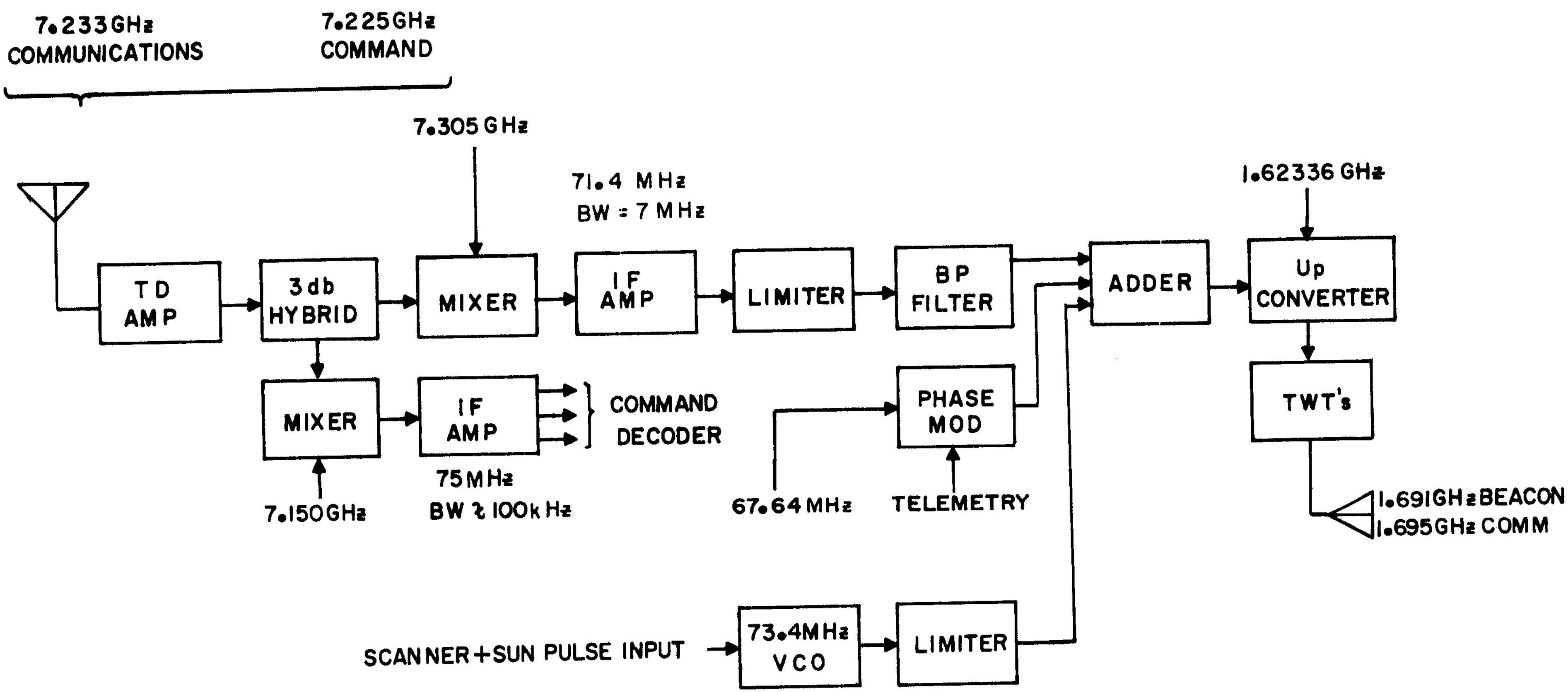


FIGURE I SOMS SPACECRAFT TRANSPONDER

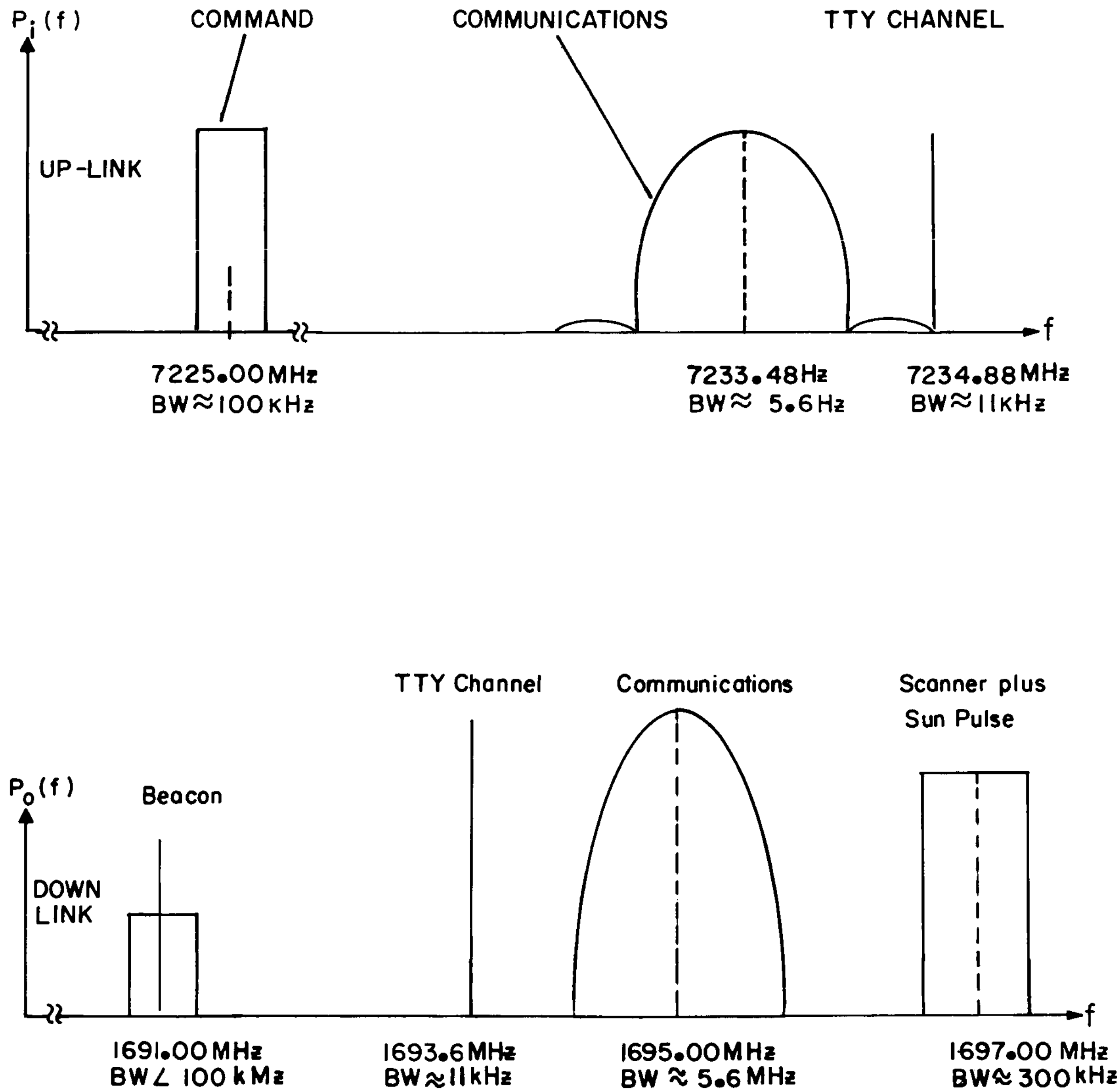
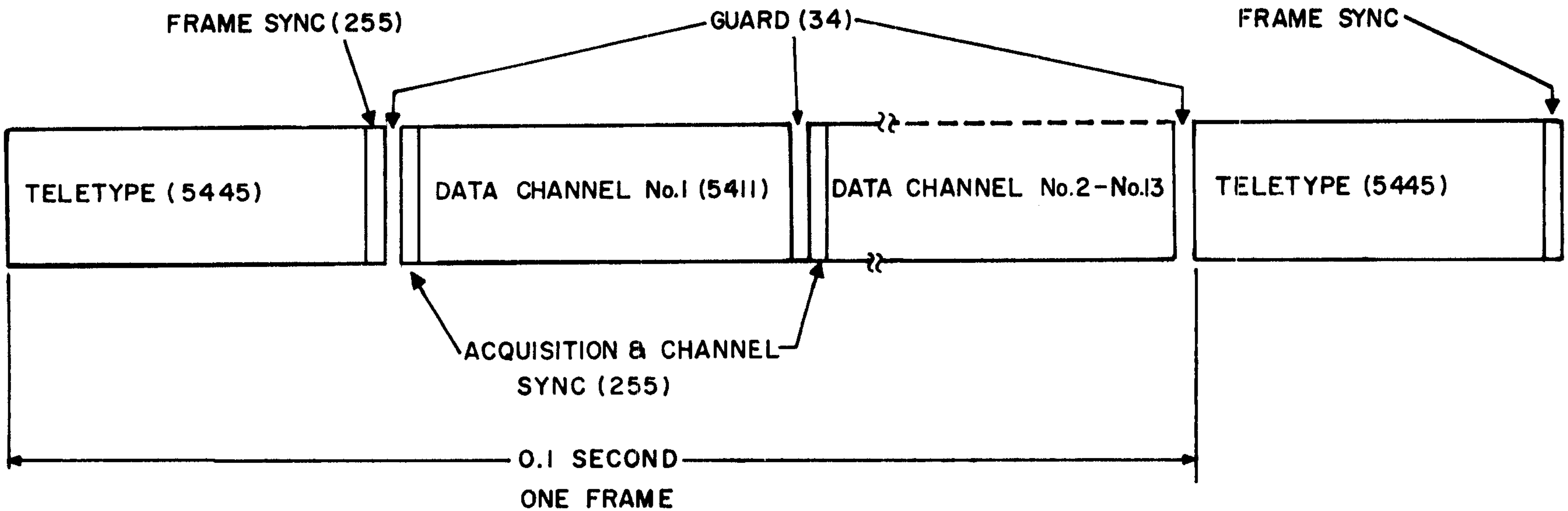


FIGURE 2. FREQUENCY CONFIGURATION



NOTE:
NUMBERS IN PARENTHESES ARE BIT PERIODS (1.251 μSECONDS PER BIT PERIOD)

FIGURE 3 SOMS TIME-DIVISION-MULTIPLEX FRAME

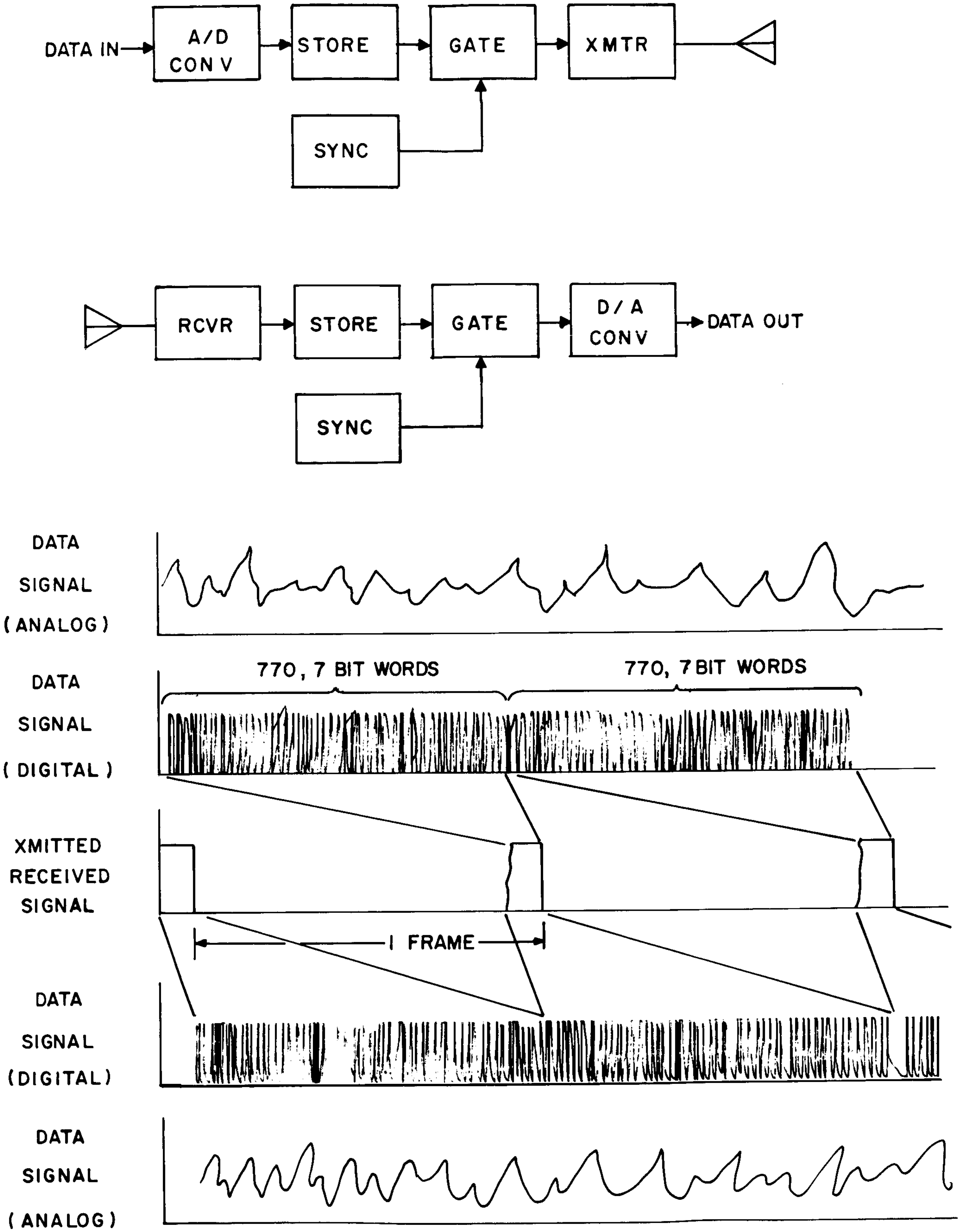
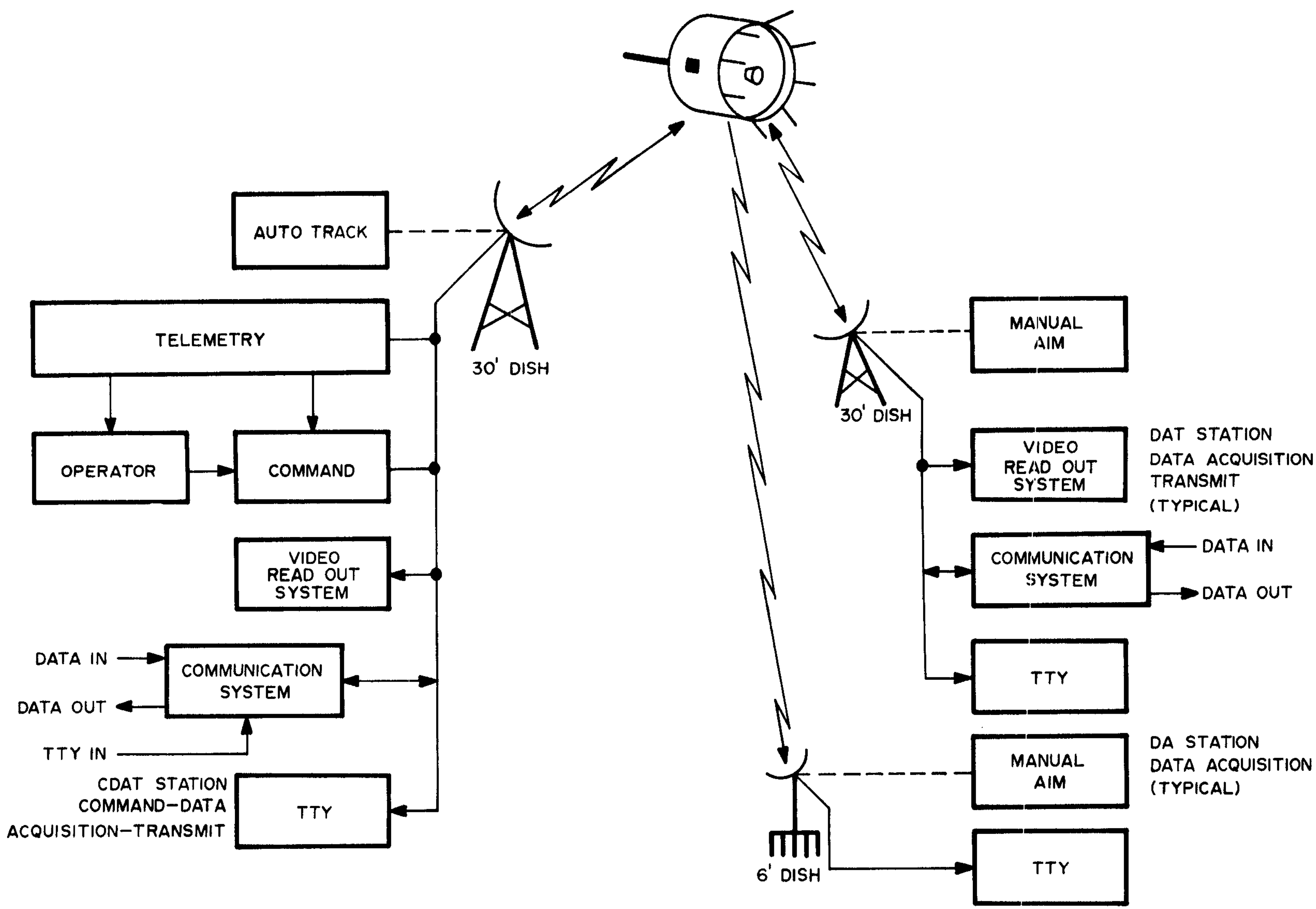


FIGURE 4. SOMS WAVEFORMS



SOMS GROUND STATIONS
FIGURE 5.

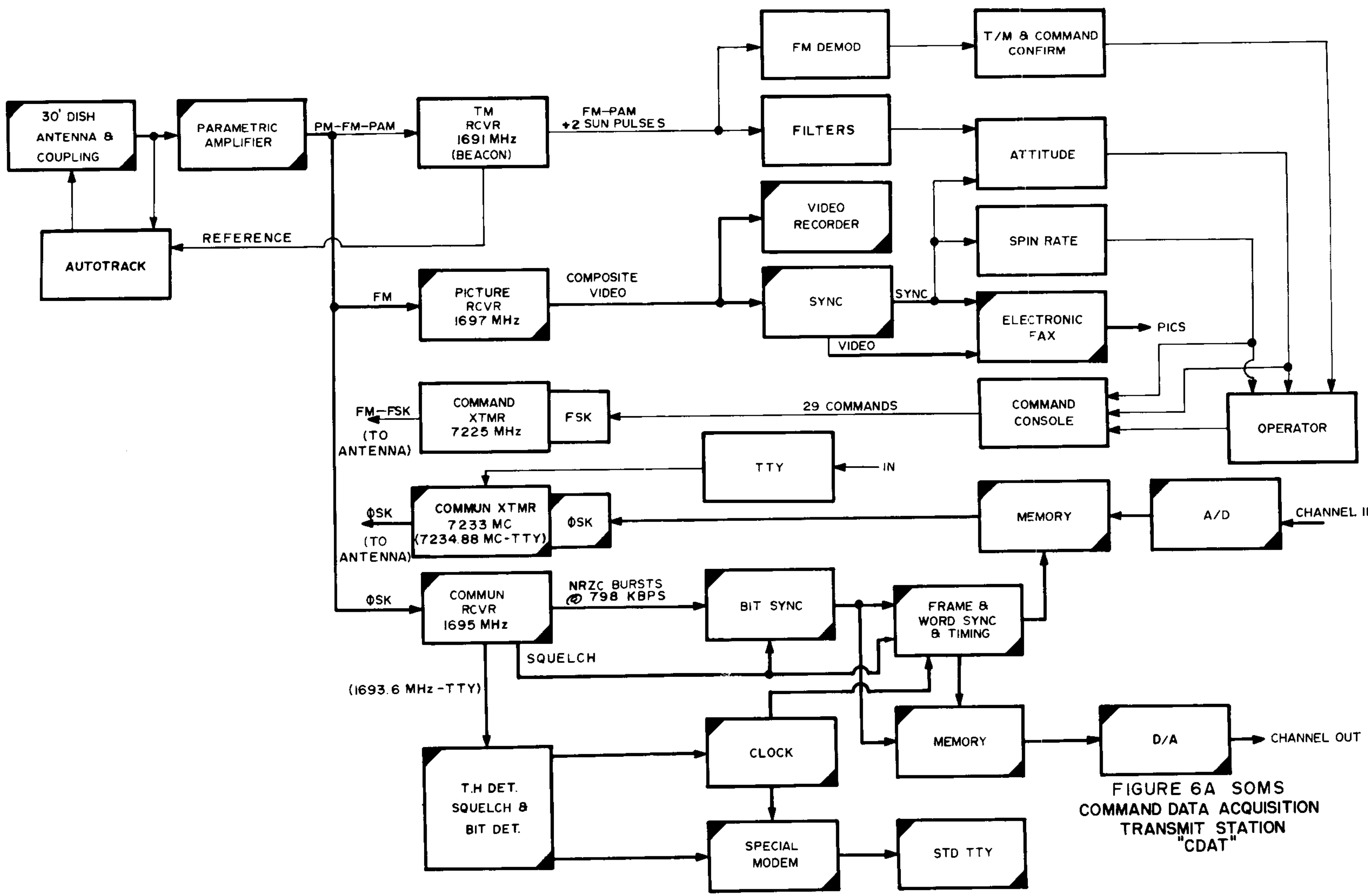


FIGURE 6A SOMS
COMMAND DATA ACQUISITION
TRANSMIT STATION
"CDAT"

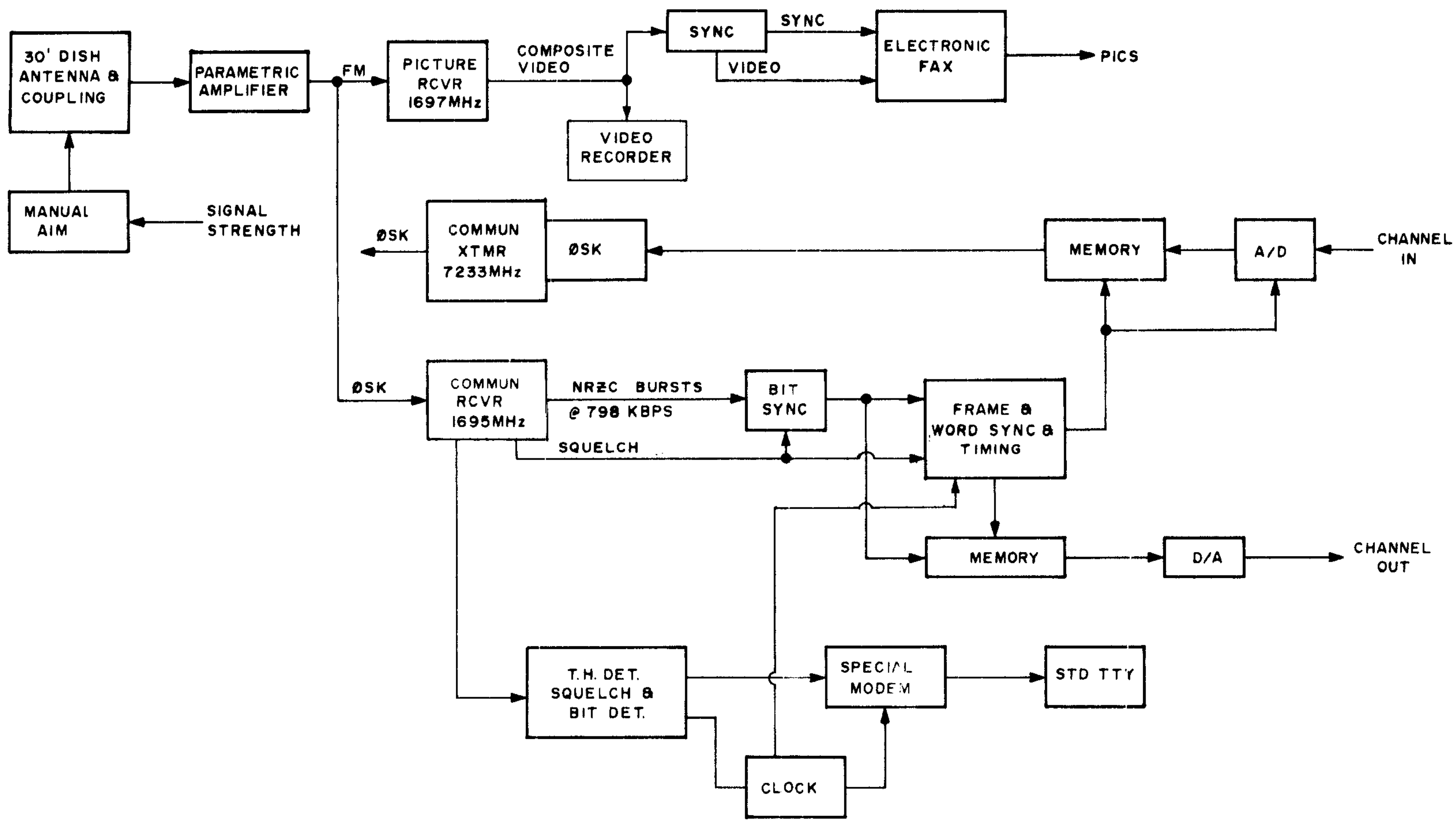


FIGURE 6B. SOMS DATA ACQUISITION TRANSMIT STATION - "DAT"

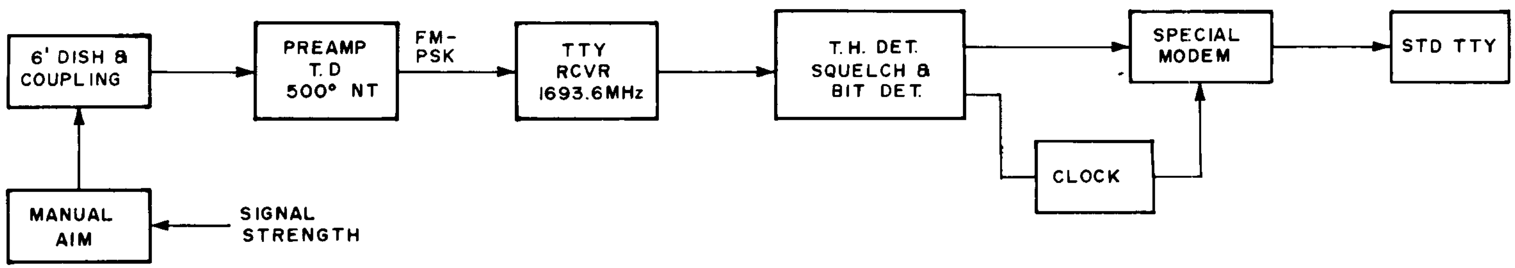
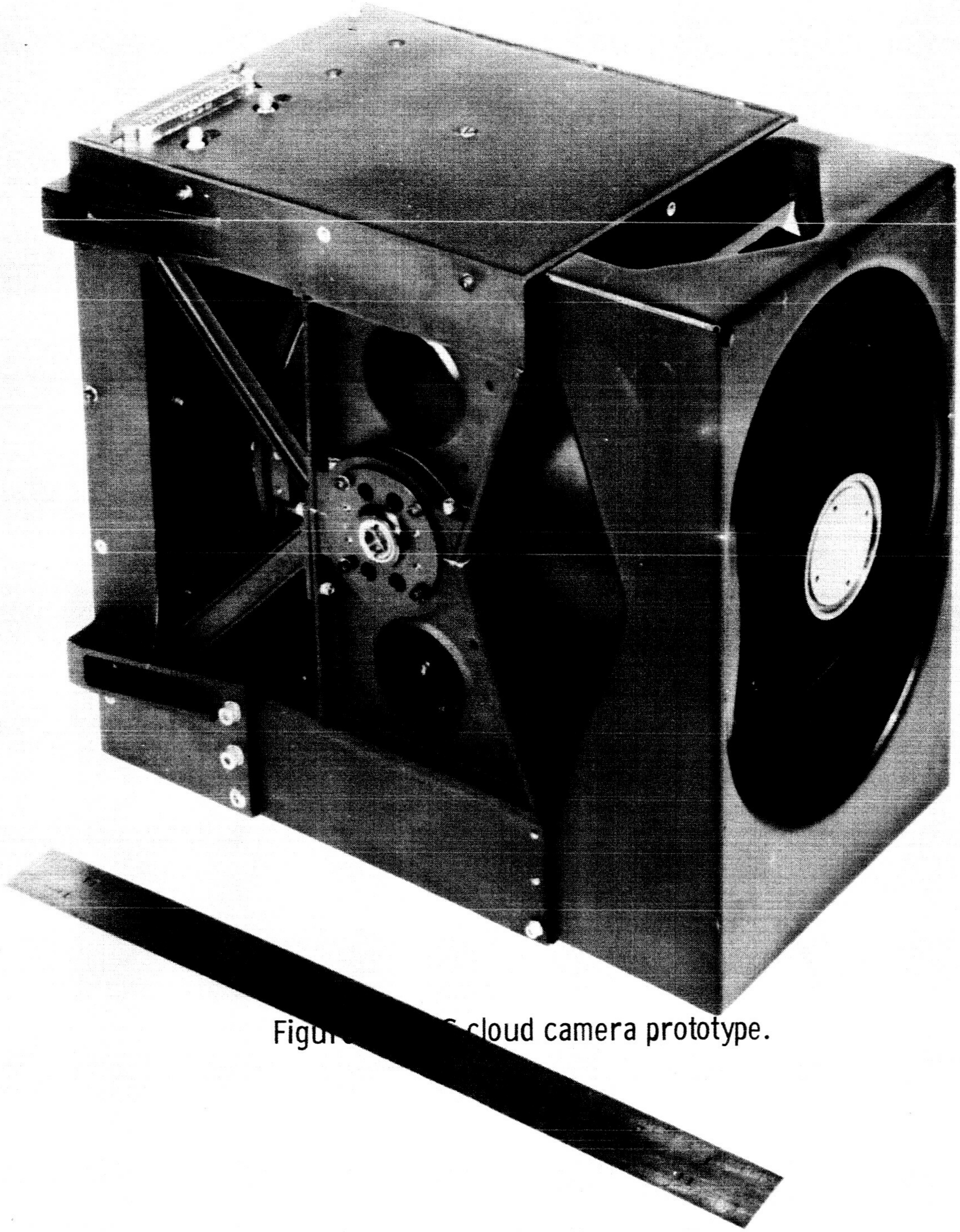


FIGURE 7. SOMS DATA ACQUISITION STATION - "DA"



Figu[illegible] cloud camera prototype.

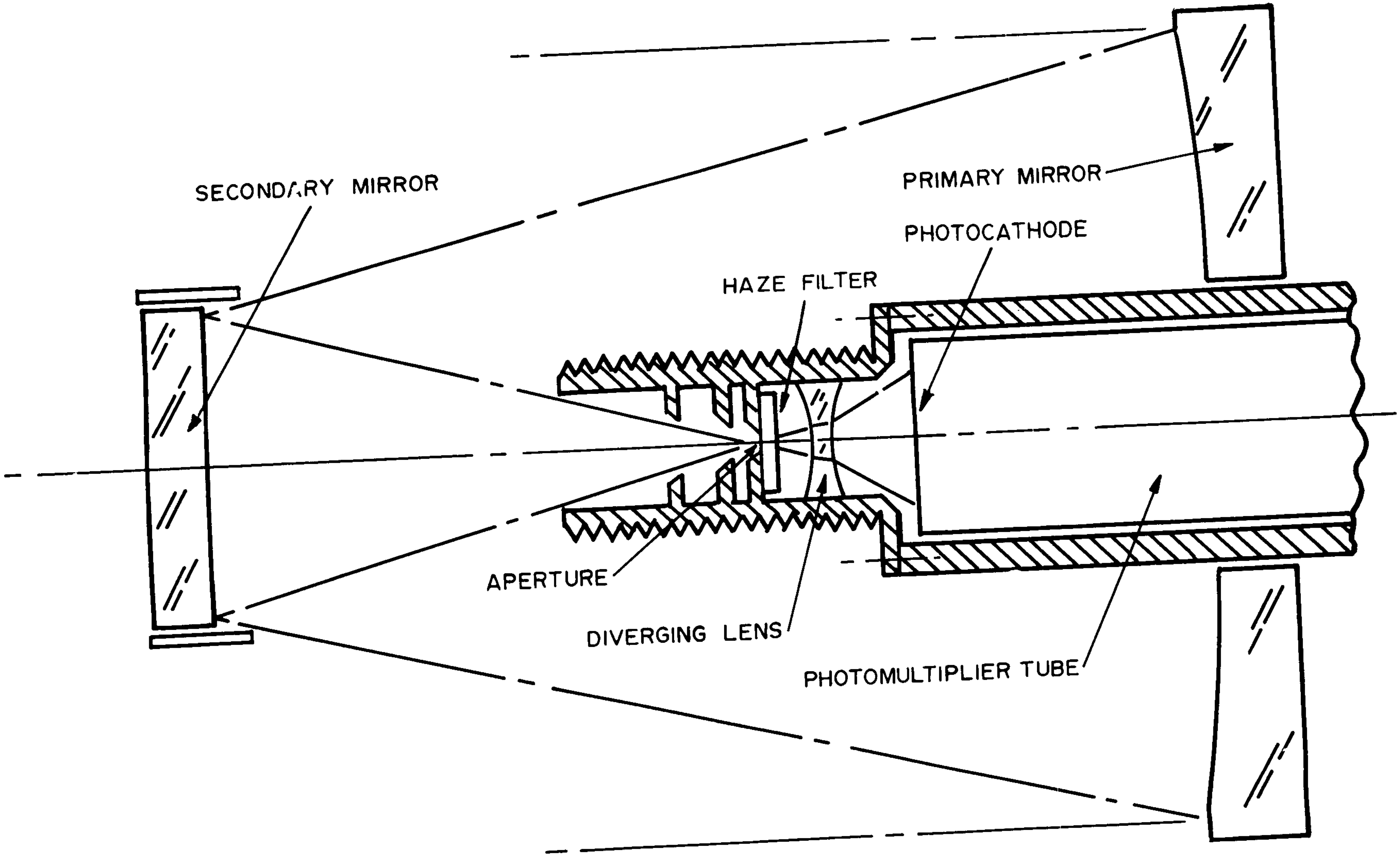


FIGURE 9. TELESCOPE PHOTOMULTIPLIER OPTICAL SYSTEM DIAGRAM

Figure 10-ATS cloud camera rear view.

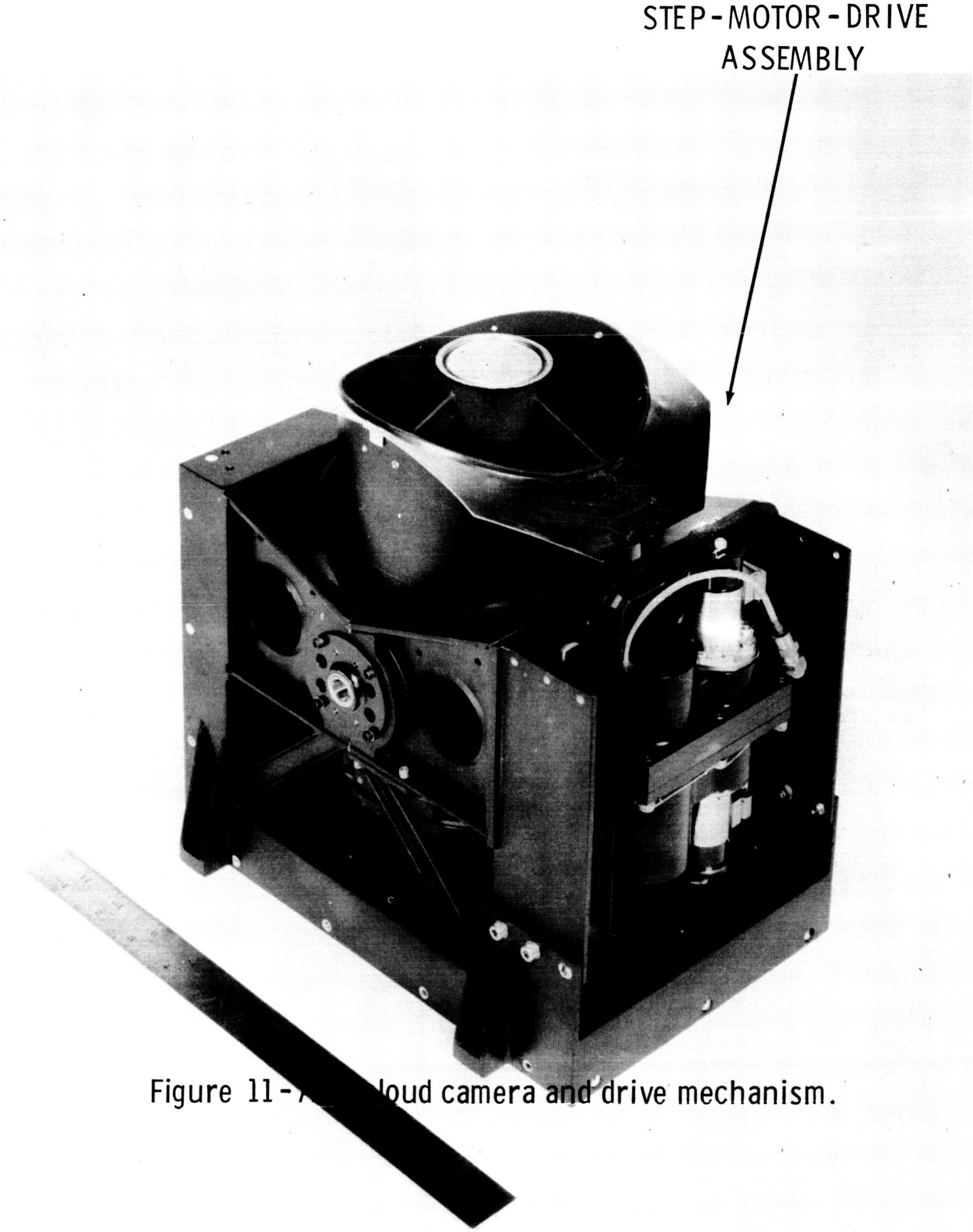


Figure 11 - A [illegible] loud camera and drive mechanism.

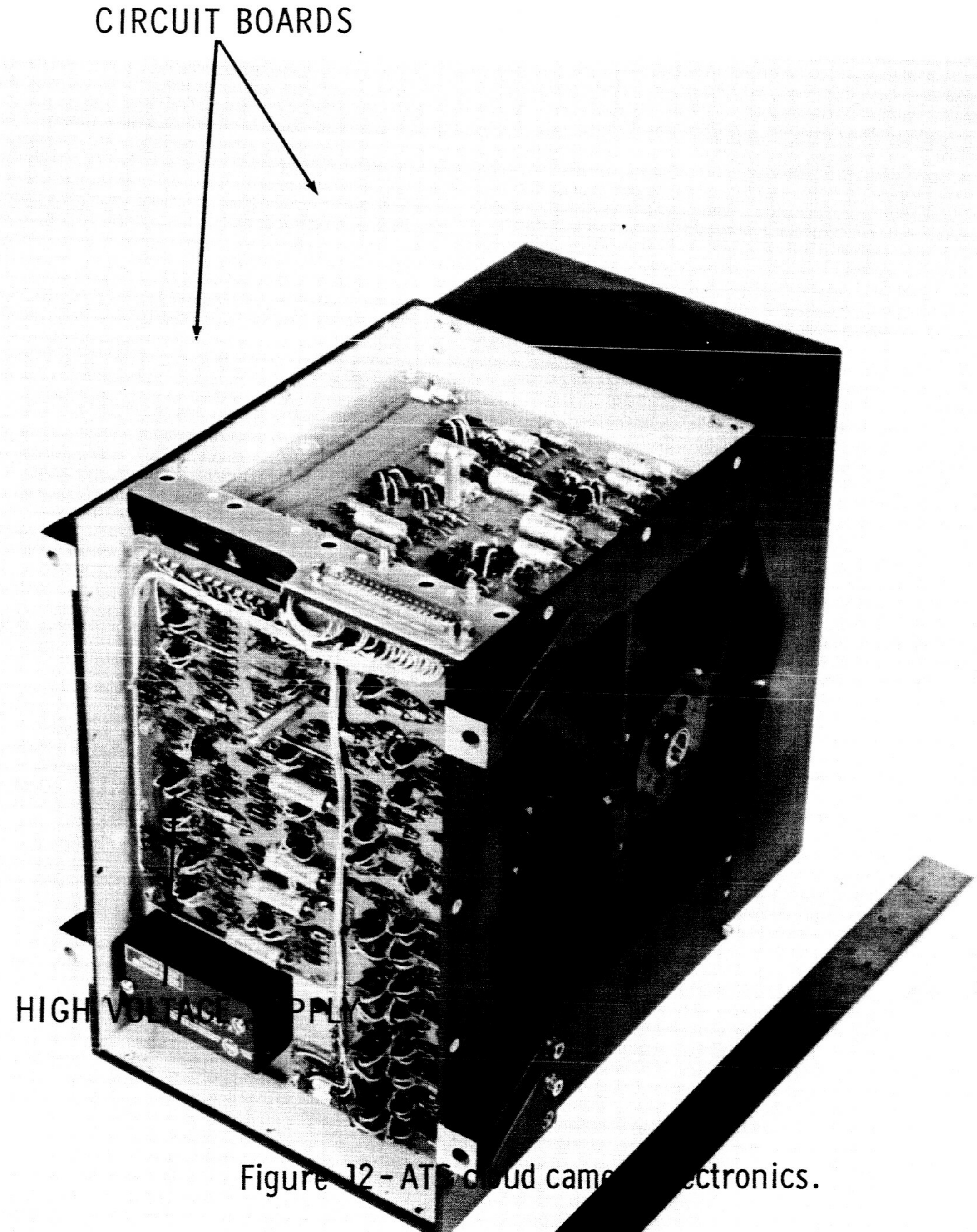


Figure 12 - ATS cloud camera electronics.

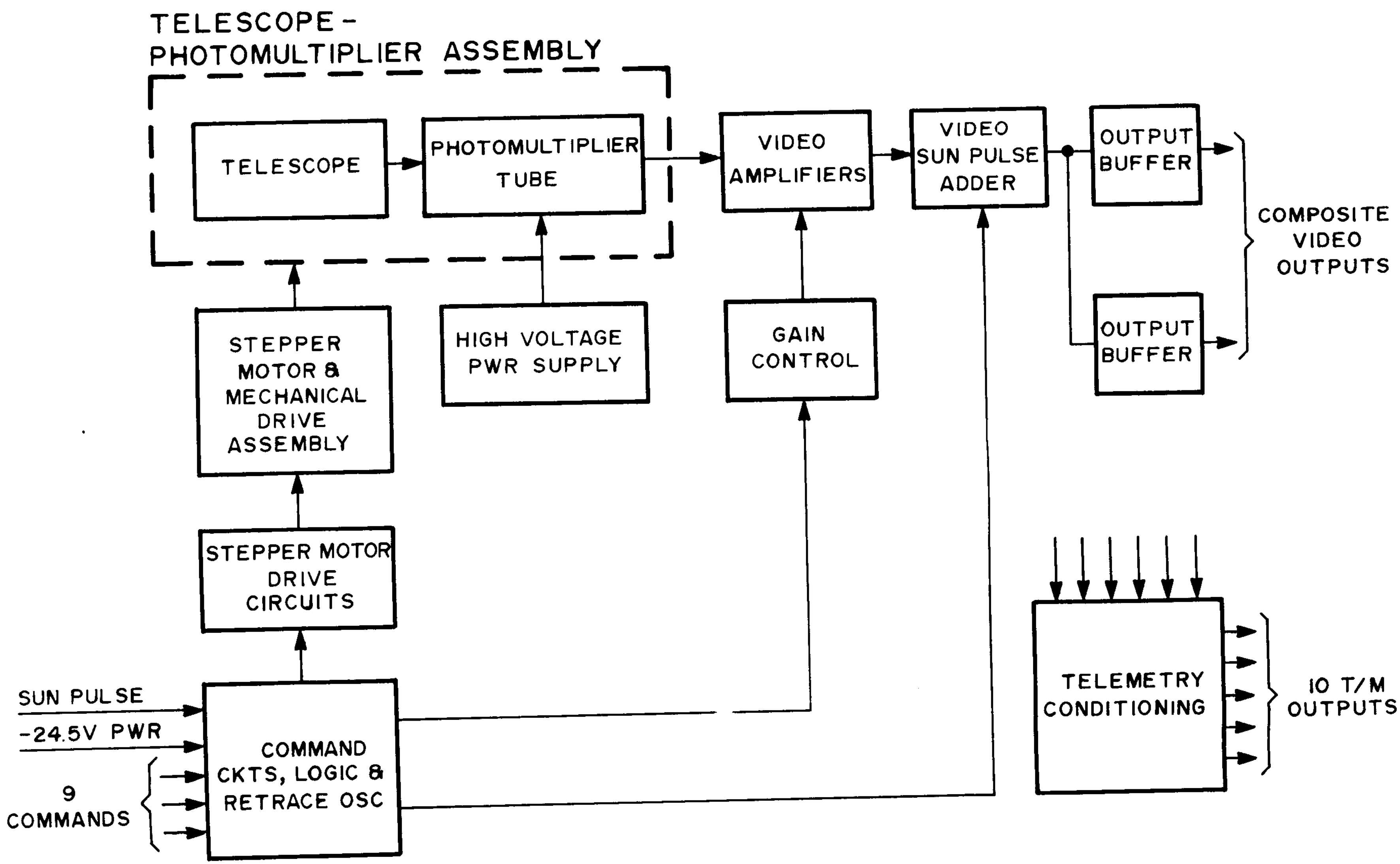
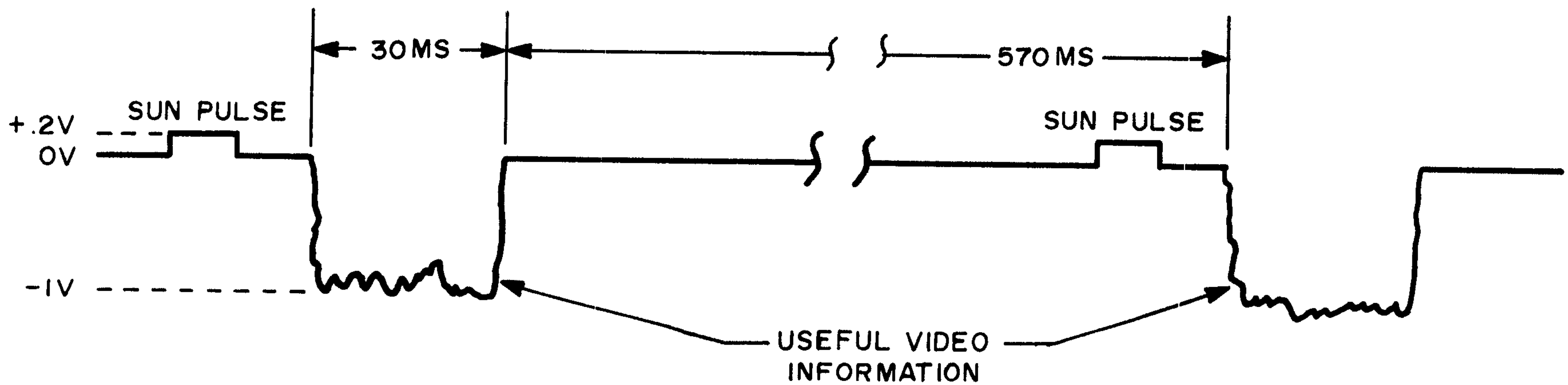
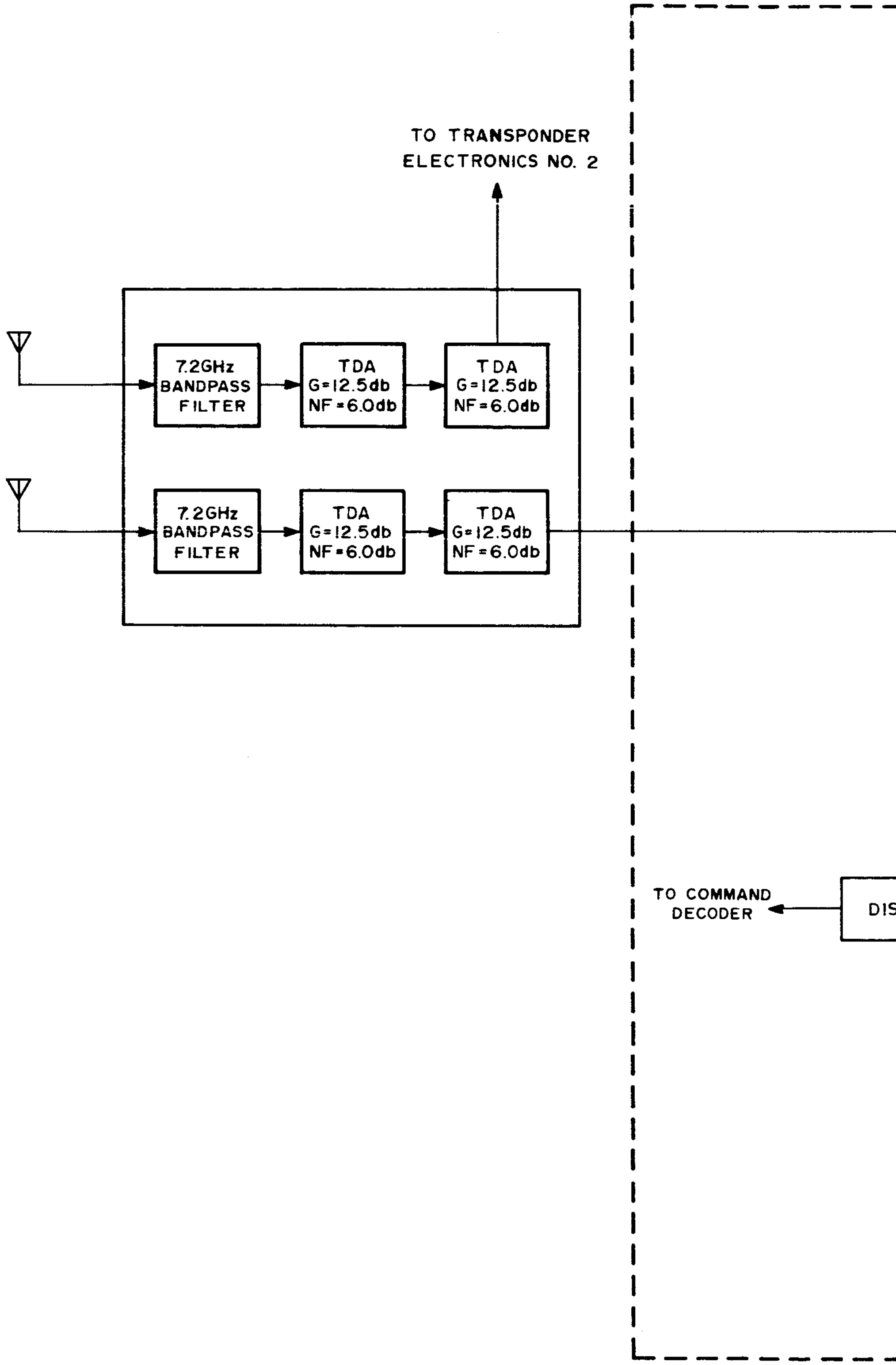


FIGURE 13. SOMS SCANNING SYSTEM BLOCK DIAGRAM

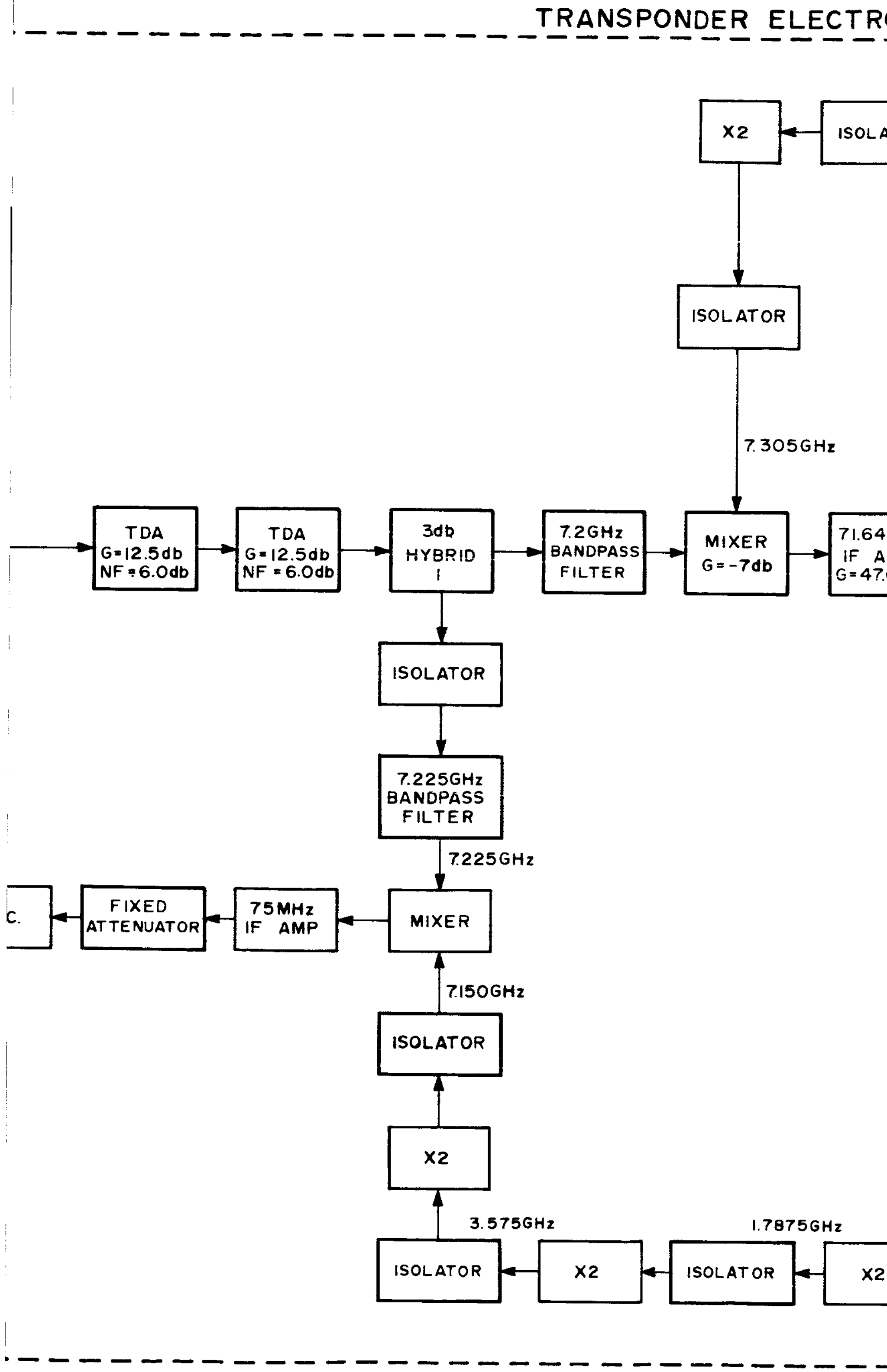


NOTE: TIMES ARE FOR 100 RPM
S/C SPIN RATE

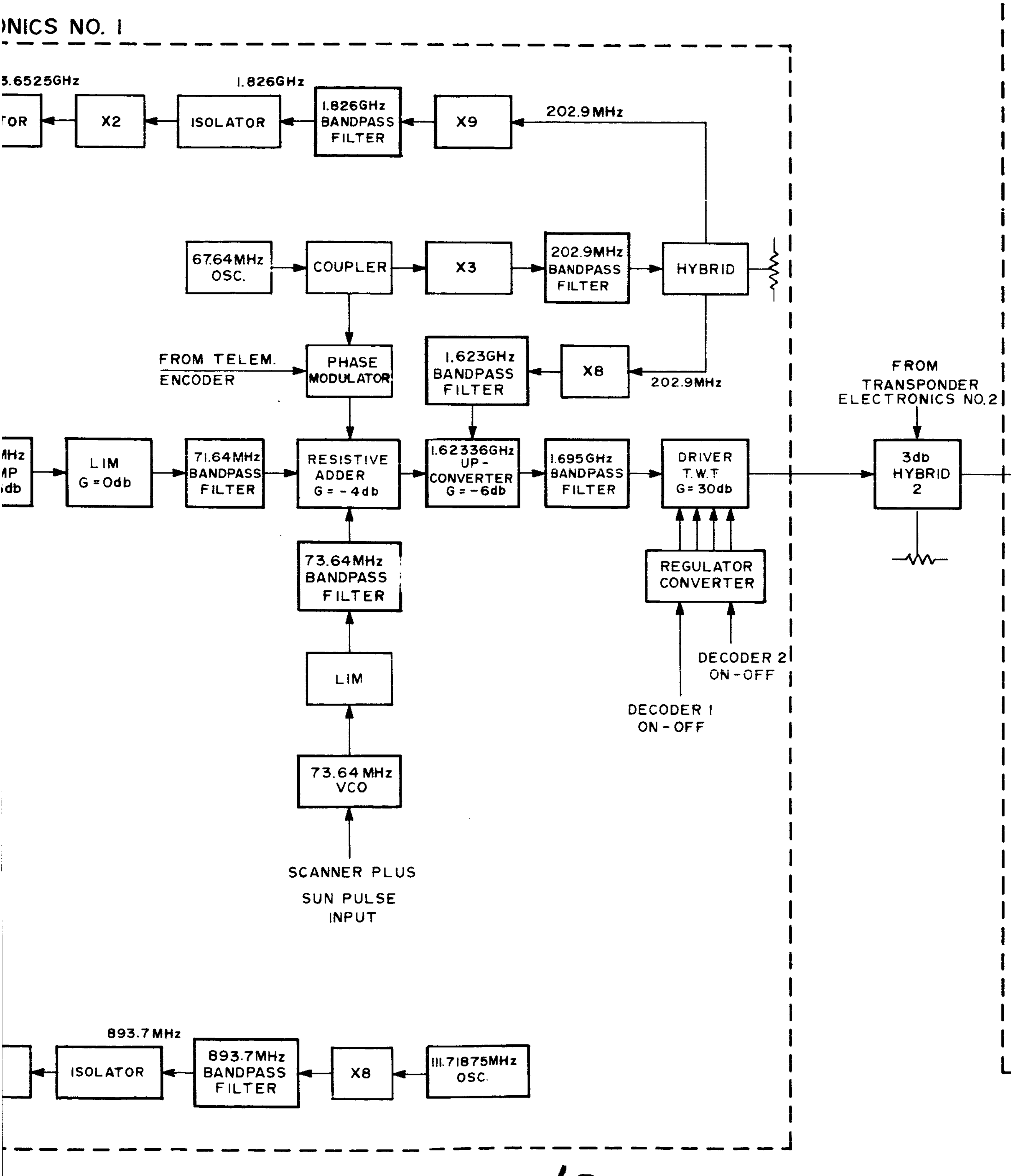
FIGURE 14. SOMS SCANNER COMPOSITE VIDEO OUTPUT FORMAT


TO TRANSPONDER ELECTRONICS NO. 2
7.2GHz BANDPASS FILTER
TDA G=12.5db NF=6.0db
TDA G=12.5db NF=6.0db
7.2GHz BANDPASS FILTER
TDA G=12.5db NF=6.0db
TDA G=12.5db NF=6.0db
TO COMMAND DECODER
DIS

15-1



TRANSPONDER ELECTR
X2
ISOLA
ISOLATOR
7.305GHz
TDA
G=12.5db
NF=6.0db
TDA
G=12.5db
NF=6.0db
3db
HYBRID
I
7.2GHz
BANDPASS
FILTER
MIXER
G=-7db
ISOLATOR
7.225GHz
BANDPASS
FILTER
7.225GHz
C.
FIXED
ATTENUATOR
75MHz
IF AMP
MIXER
7.150GHz
ISOLATOR
X2
3.575GHz
1.7875GHz
ISOLATOR
X2
ISOLATOR
X2



NICS NO. 1
3.6525GHz
TOR
X2
1.826GHz
ISOLATOR
1.826GHz BANDPASS FILTER
X9
202.9MHz
67.64MHz OSC.
COUPLER
X3
202.9MHz BANDPASS FILTER
HYBRID
FROM TELEM. ENCODER
PHASE MODULATOR
1.623GHz BANDPASS FILTER
X8
202.9MHz
FROM TRANSPONDER ELECTRONICS NO.2
MHz
MP
db
LIM G = 0db
71.64MHz BANDPASS FILTER
RESISTIVE ADDER G = -4db
1.62336GHz UP-CONVERTER G = -6db
1.695GHz BANDPASS FILTER
DRIVER T.W.T G = 30db
3db HYBRID 2
73.64MHz BANDPASS FILTER
REGULATOR CONVERTER
DECODER 2 ON-OFF
LIM
DECODER 1 ON-OFF
73.64 MHz VCO
SCANNER PLUS SUN PULSE INPUT
893.7 MHz
ISOLATOR
893.7MHz BANDPASS FILTER
X8
111.71875MHz OSC.

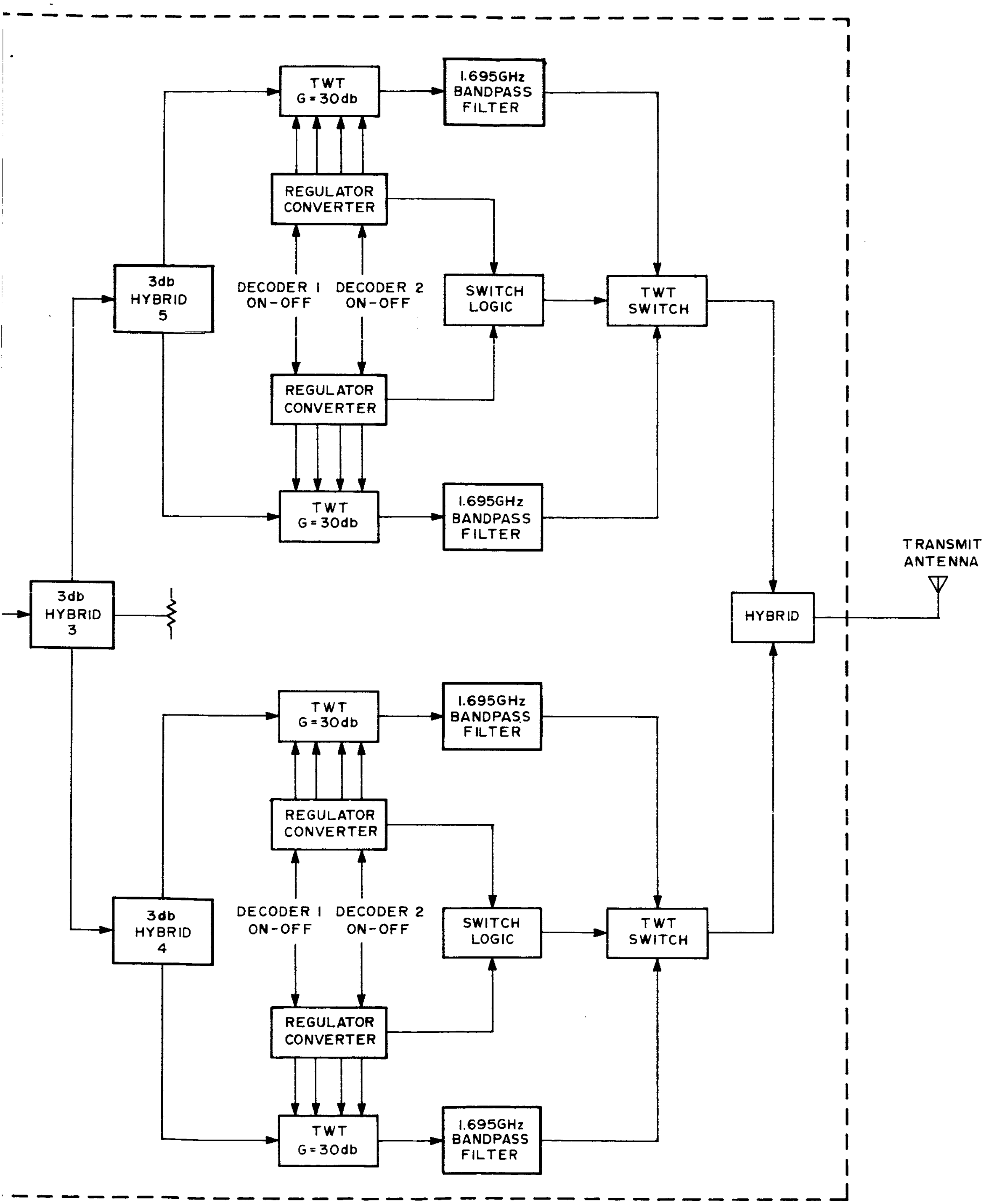


FIGURE 15. SOMS SPACECRAFT TRANSPONDER

4

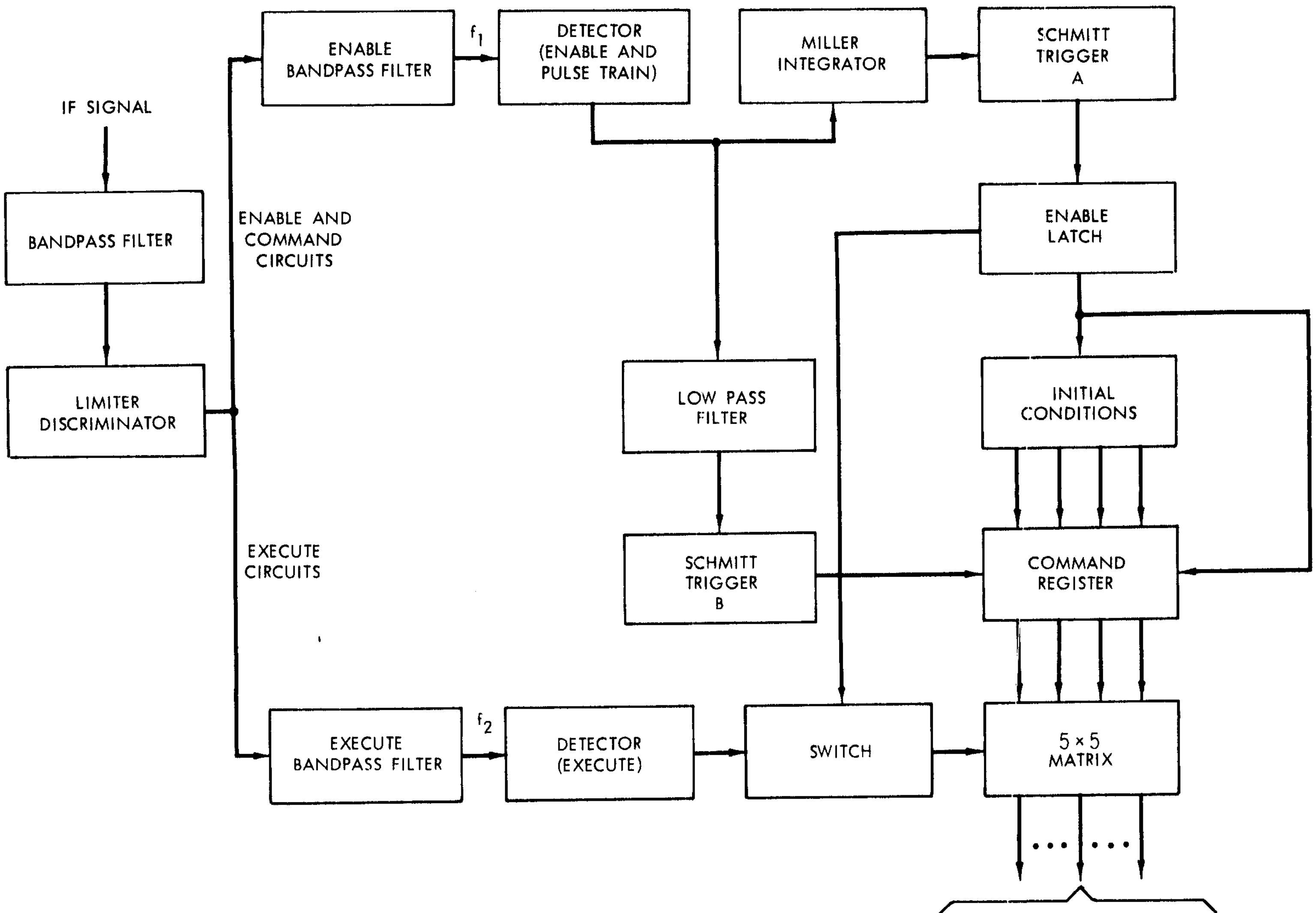


FIGURE 16. S O M S SPACECRAFT COMMAND SUBSYSTEM

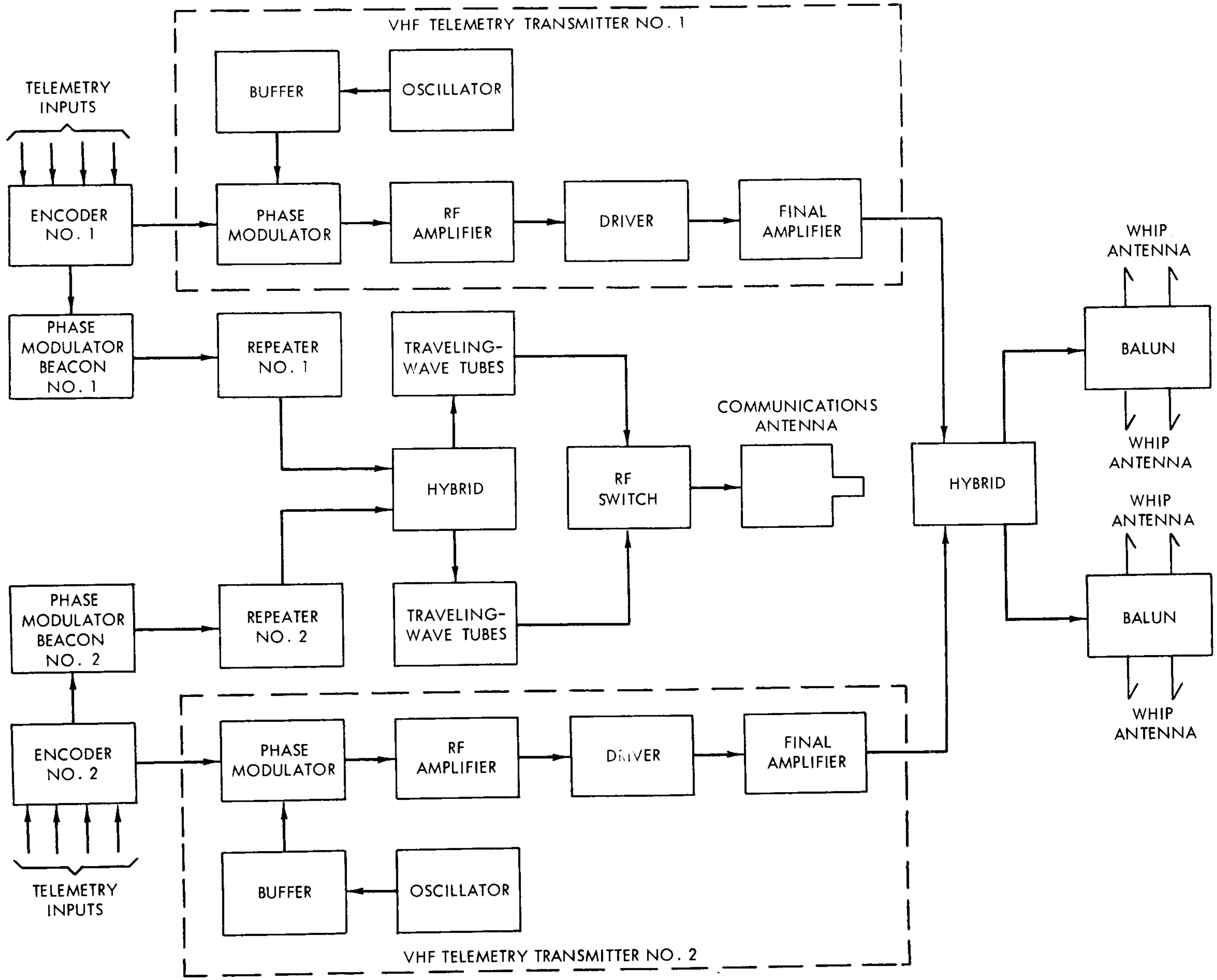


FIGURE 17. SOMS SPACECRAFT TELEMETRY SUBSYSTEM

STATION	ONE 100 WPM TTY	13 DATA CHANNELS 3.85 kHz EACH		SCANNER VIDEO DATA	SCANNER DATA ON FACSIMILE (ONE OF 13 DATA CHANNELS)
		RECEIVE	TRANSMIT		
CDAT	YES	ALL	ALL	YES	ORIGINATES TRANSMISSION
DAT	YES	1—13 MODULAR	1—13 MODULAR	OPTIONAL	OPTIONAL
DA	YES	NO	NO	NO	NO

FIGURE 18. STATION CAPABILITY

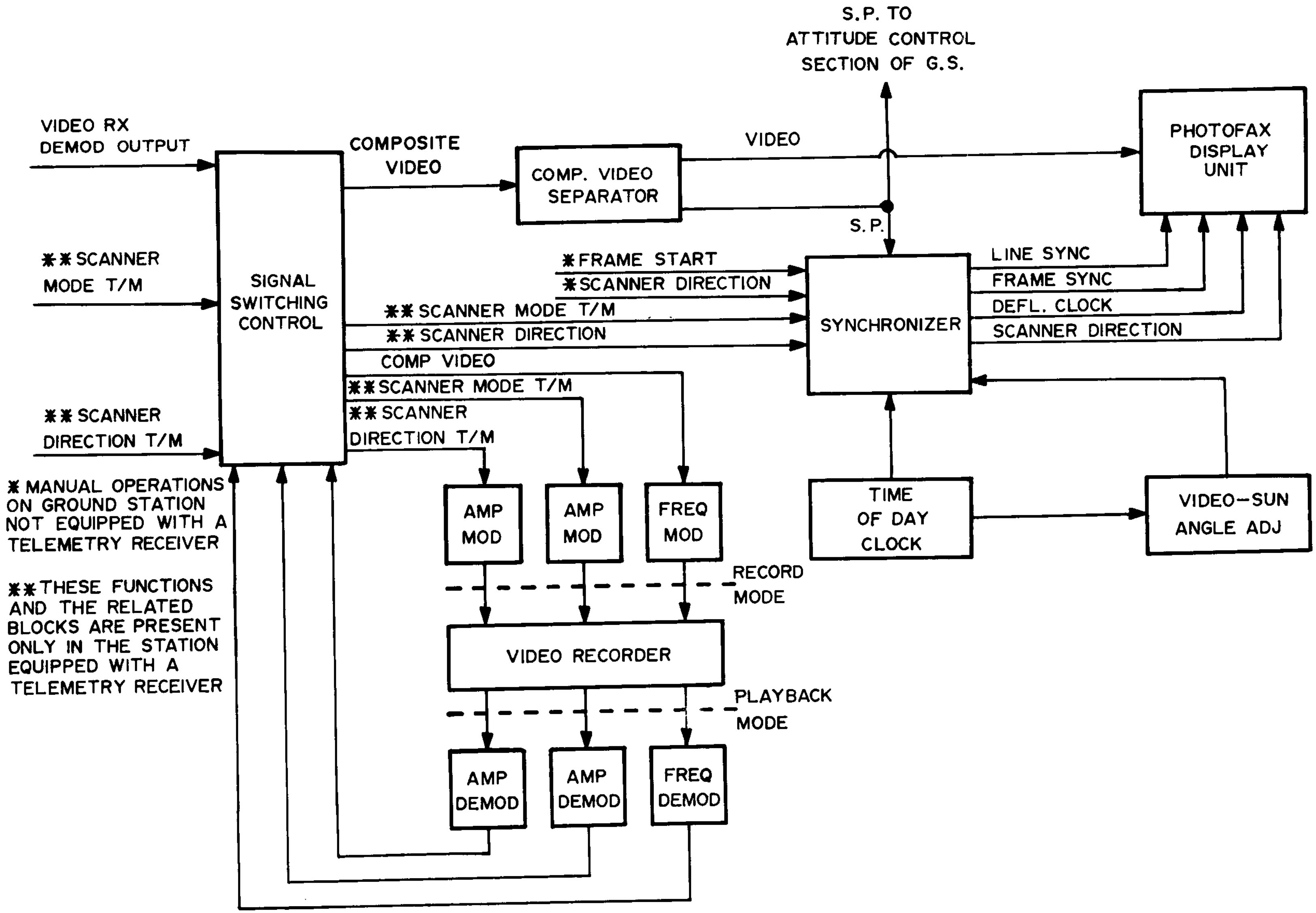


FIGURE 19. VIDEO RECORD AND DISPLAY GROUND STATION BLOCK DIAGRAM

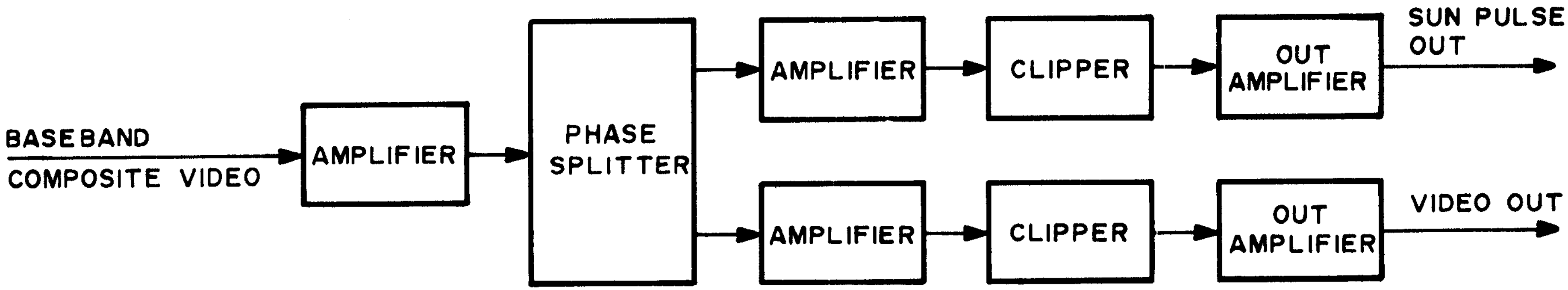


FIGURE 20. COMPOSITE VIDEO SEPARATOR

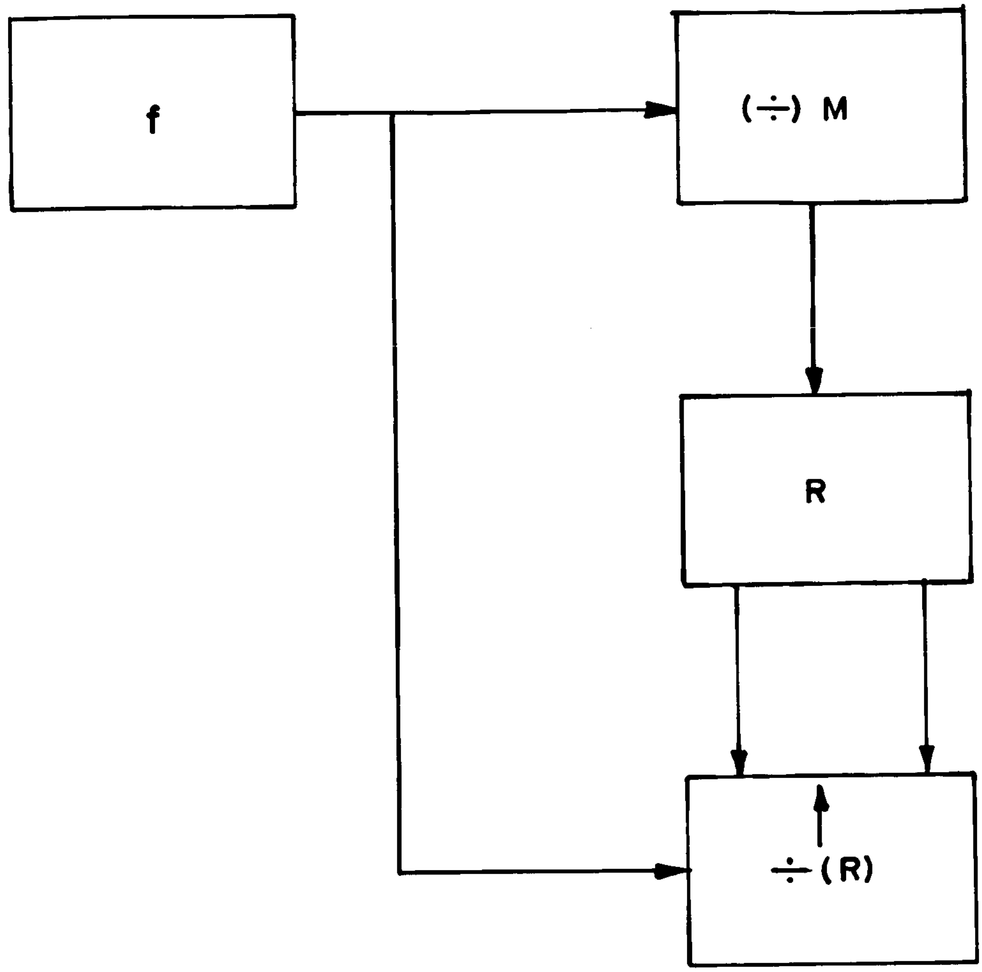


FIGURE 21
SIMPLIFED SYNCHRONIZER
FREQUENCY CONTROL

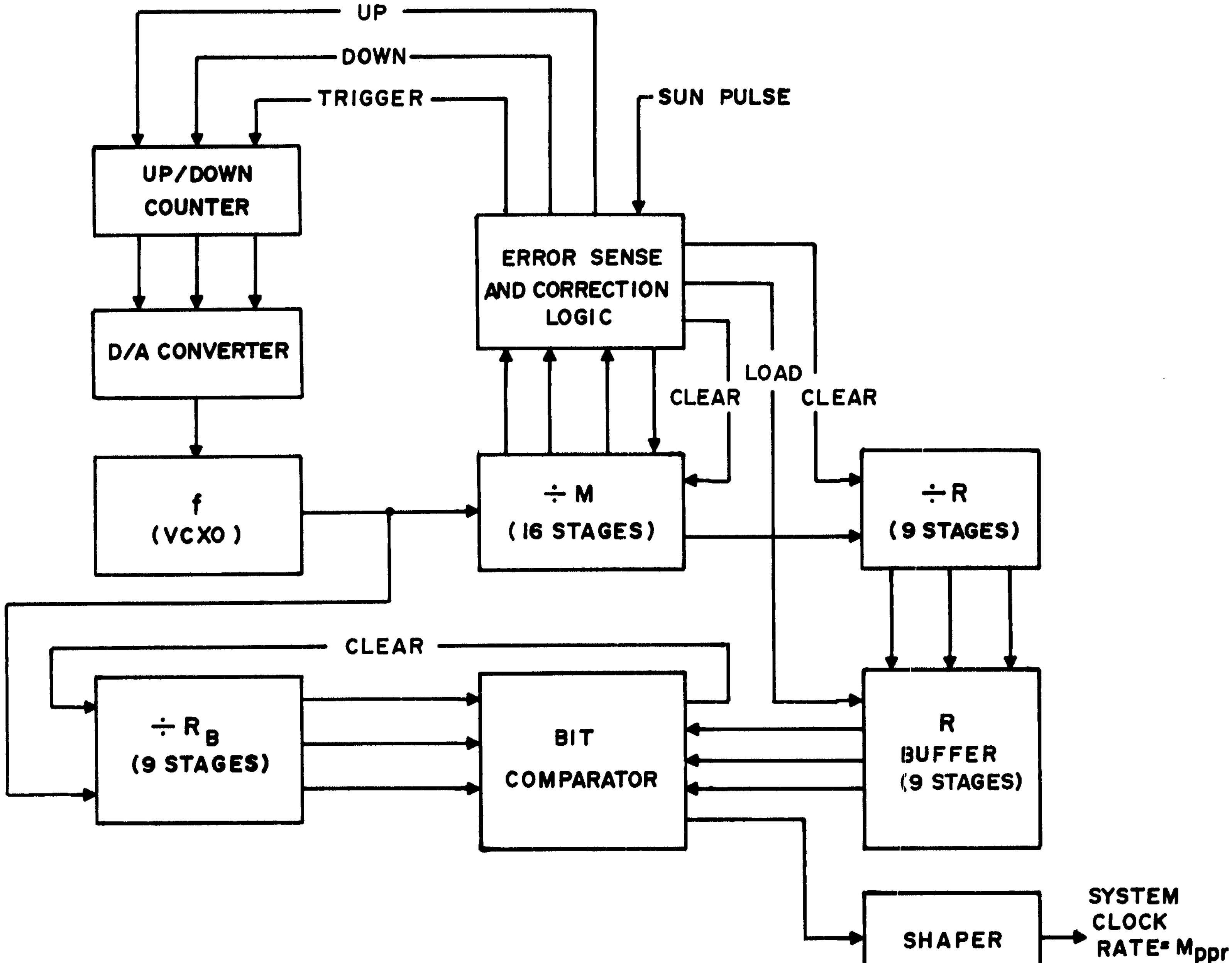


FIGURE 22. SYNCHRONIZER FREQUENCY CONTROL BLOCK DIAGRAM

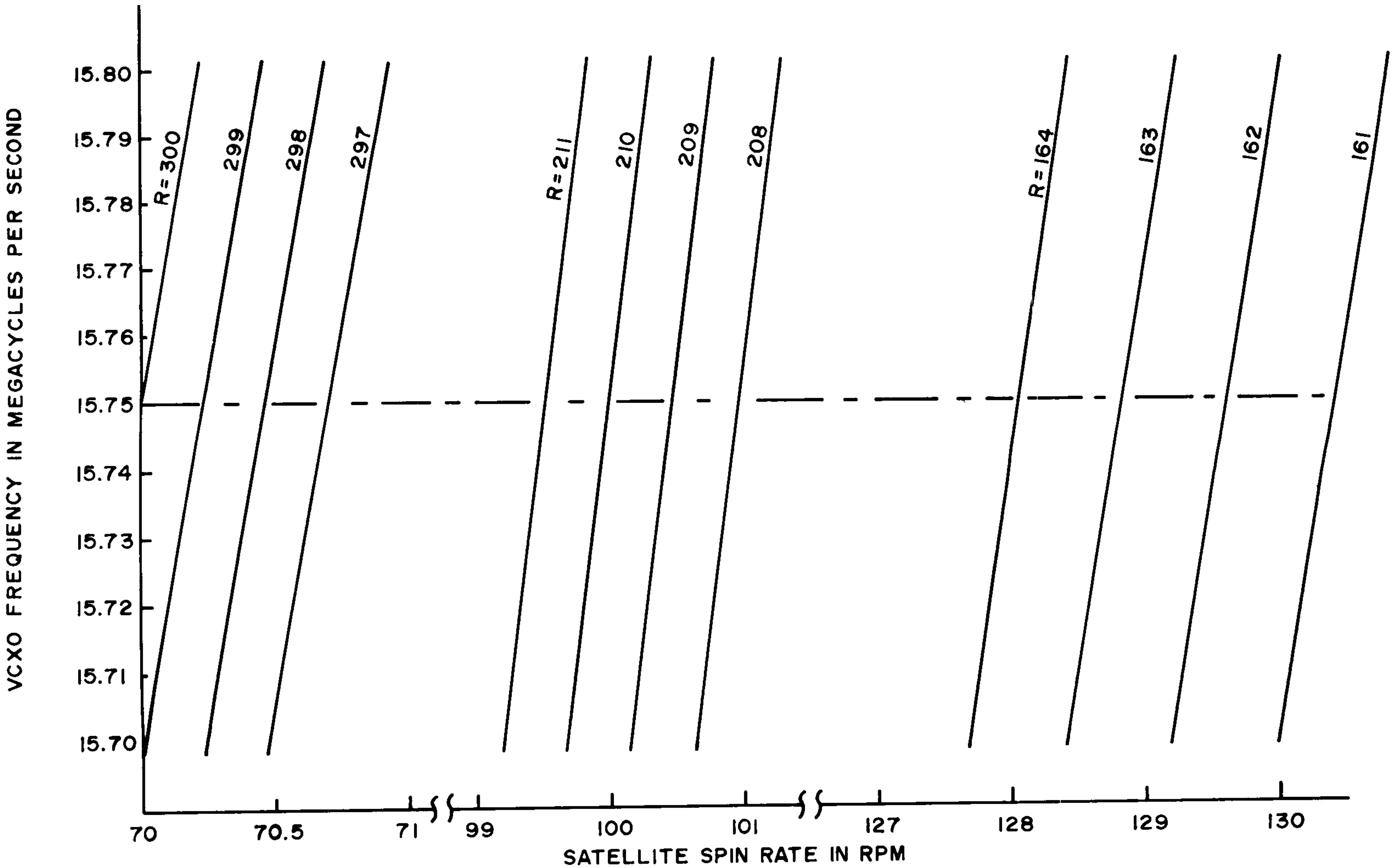


FIGURE 23. VCXO FREQUENCY vs. S/C SPIN RATE
SHOWING CHANGES IN f AND R
M = 45000 fo = 15.75 MHz

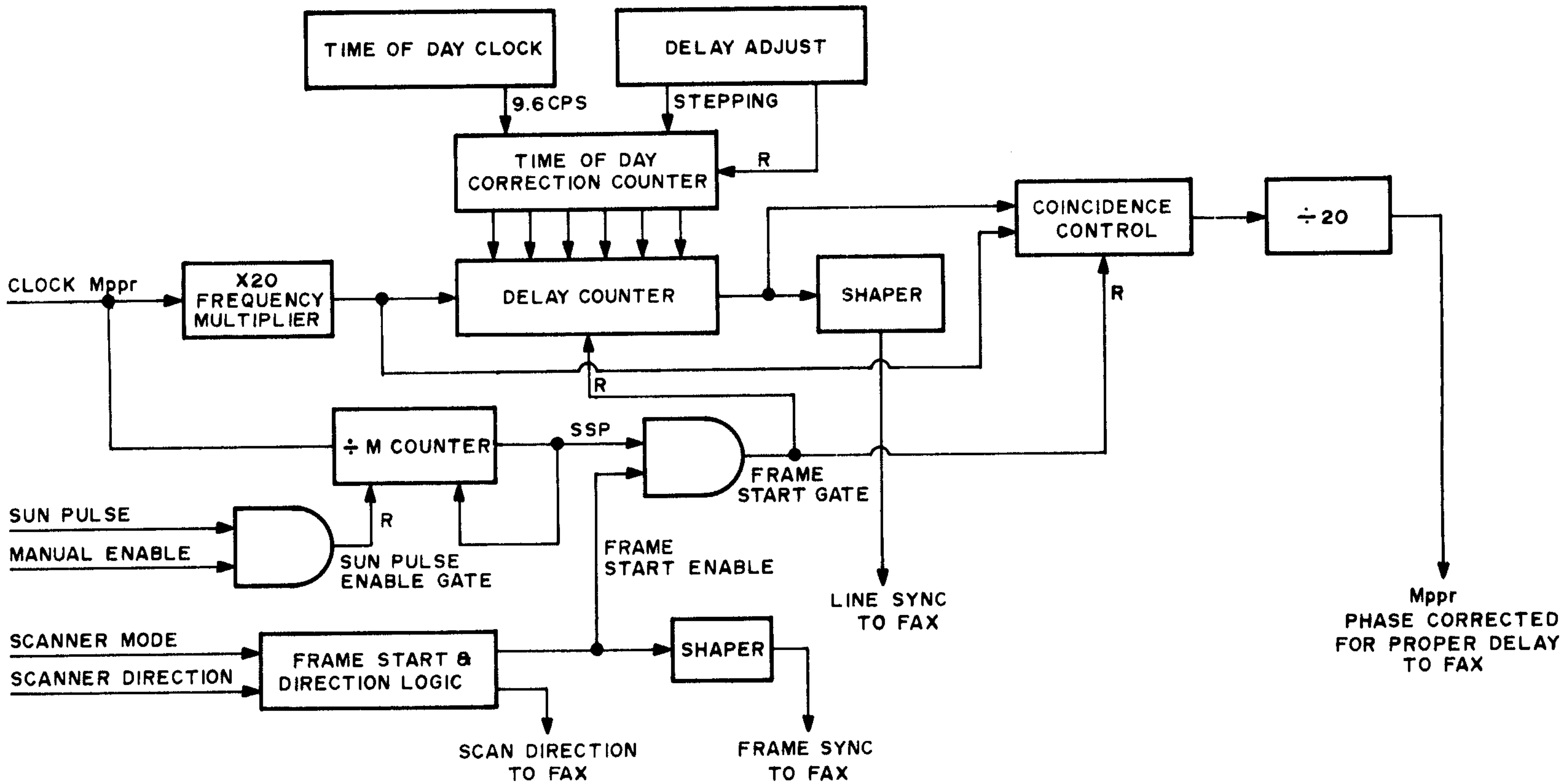


FIGURE 24. PHASING AND CONTROL PORTION OF VIDEO SYNCHRONIZER

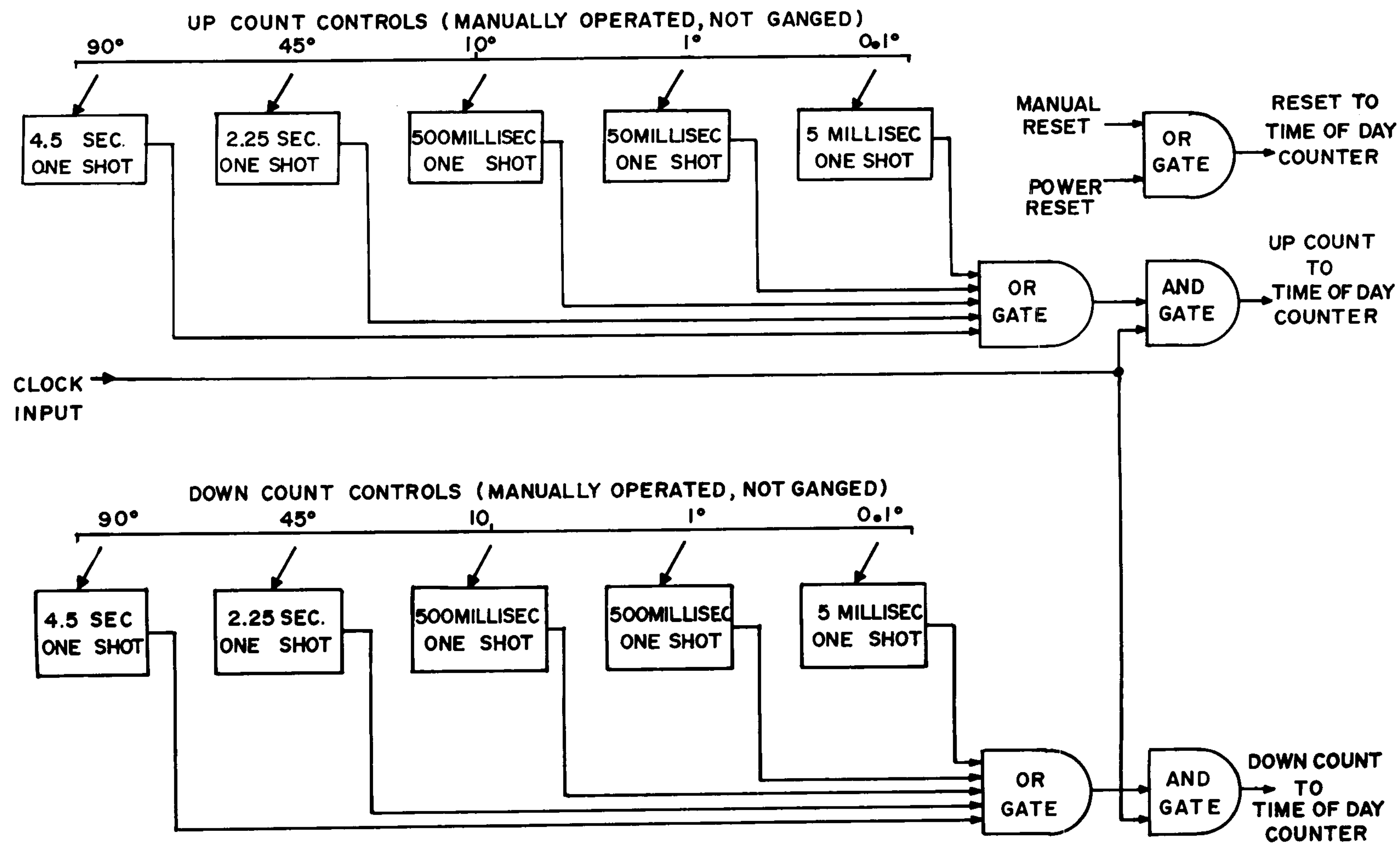
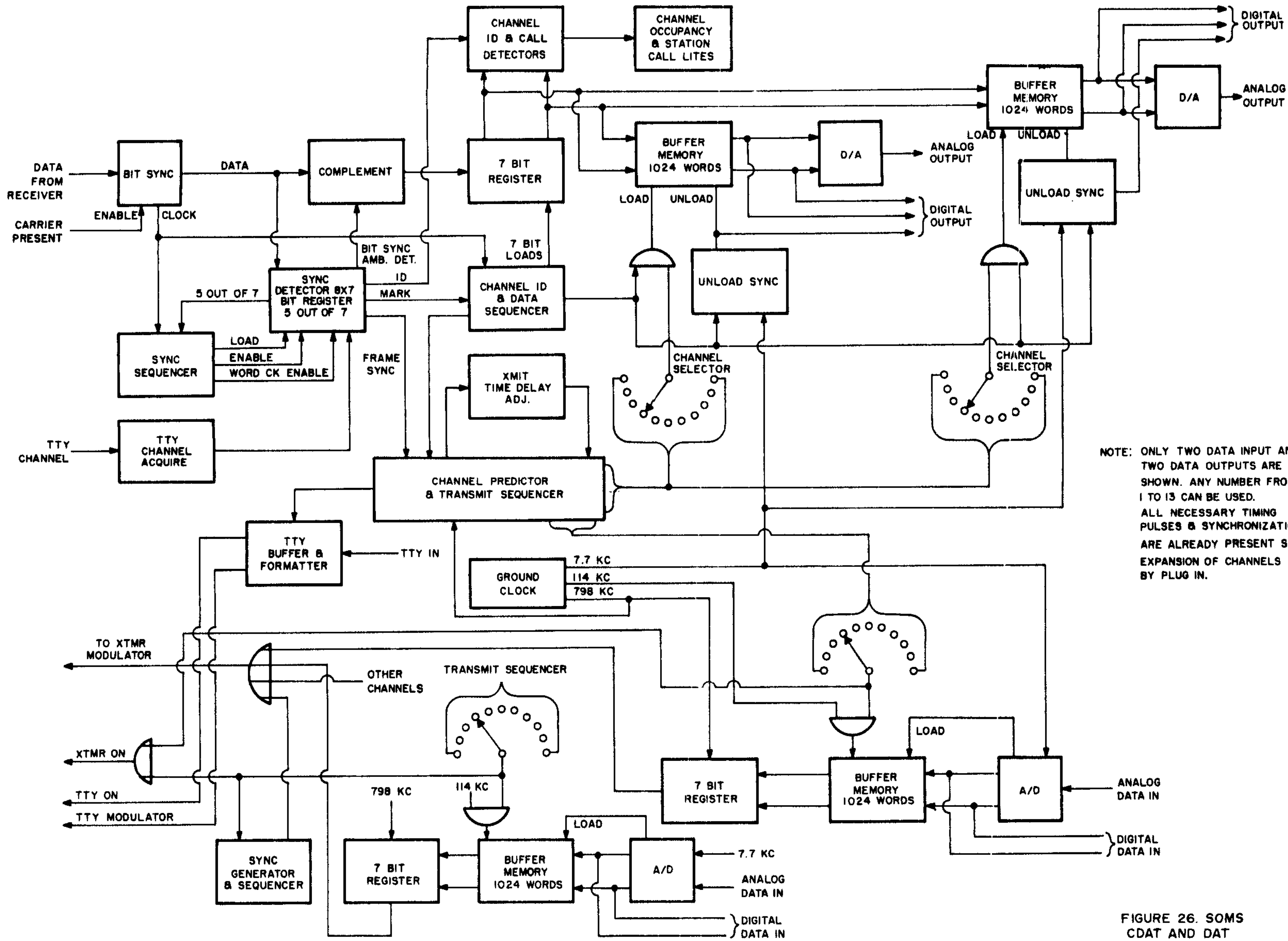


FIGURE 25. SUN-VIDEO ANGLE ADJUST BLOCK DIAGRAM



NOTE: ONLY TWO DATA INPUT AND TWO DATA OUTPUTS ARE SHOWN. ANY NUMBER FROM 1 TO 13 CAN BE USED.
ALL NECESSARY TIMING PULSES & SYNCHRONIZATION ARE ALREADY PRESENT SO EXPANSION OF CHANNELS IS BY PLUG IN.

FIGURE 26. SOMS CDAT AND DAT SYNCHRONIZATION AND DATA HANDLING

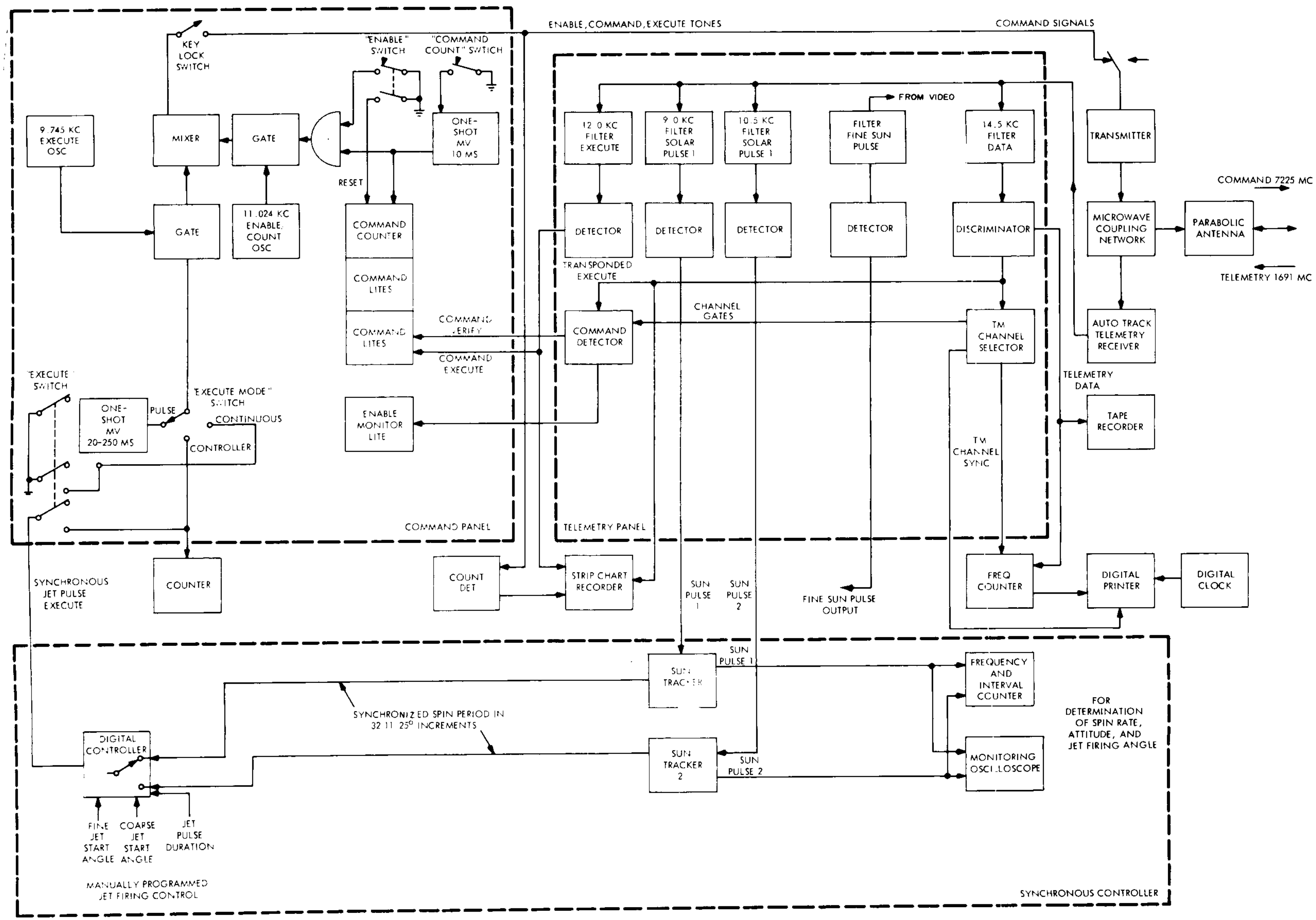


FIGURE 27. S O M S GROUND COMMAND TELEMETRY EQUIPMENT

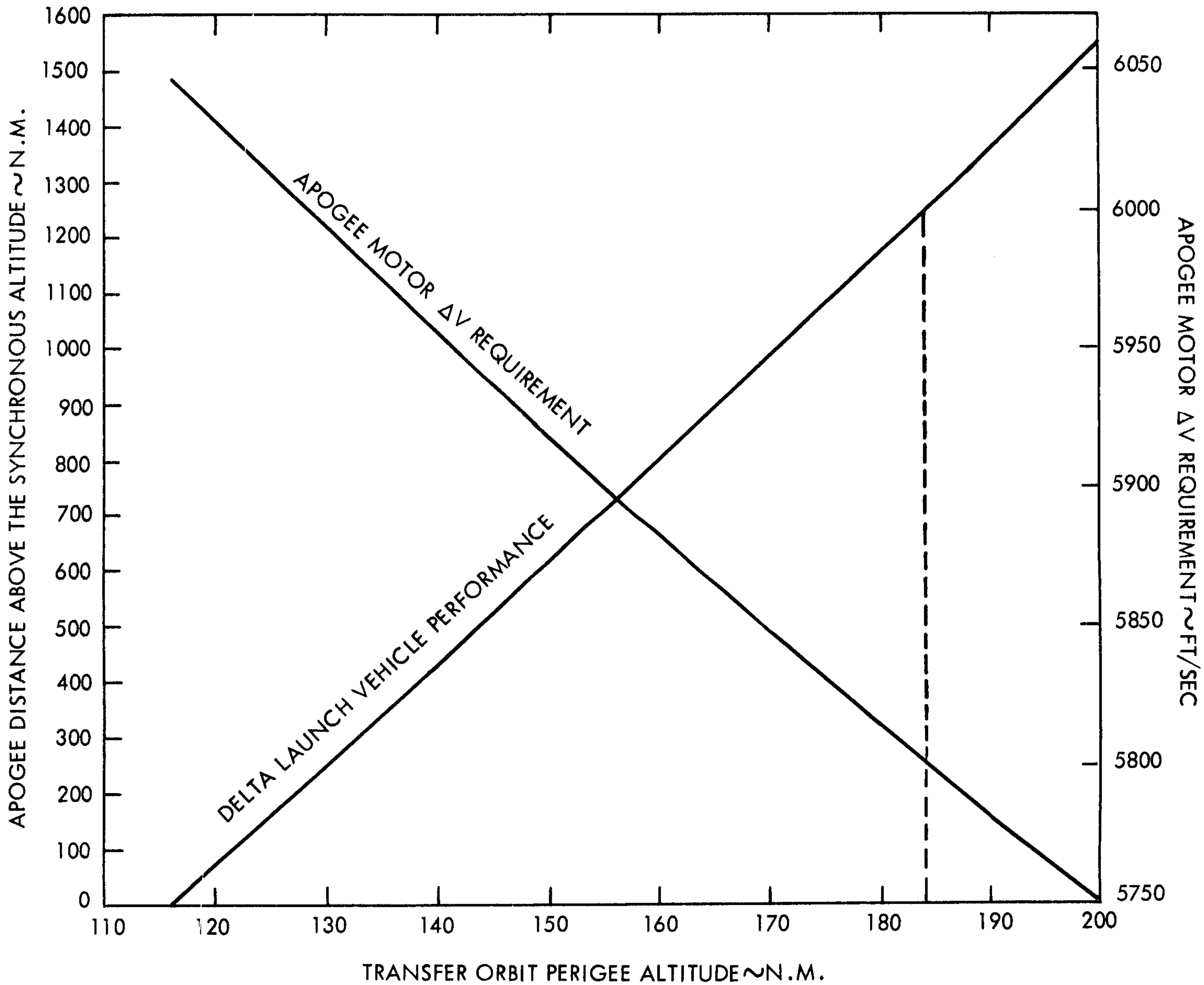


FIGURE 29. SOMS PROPULSION REQUIREMENTS

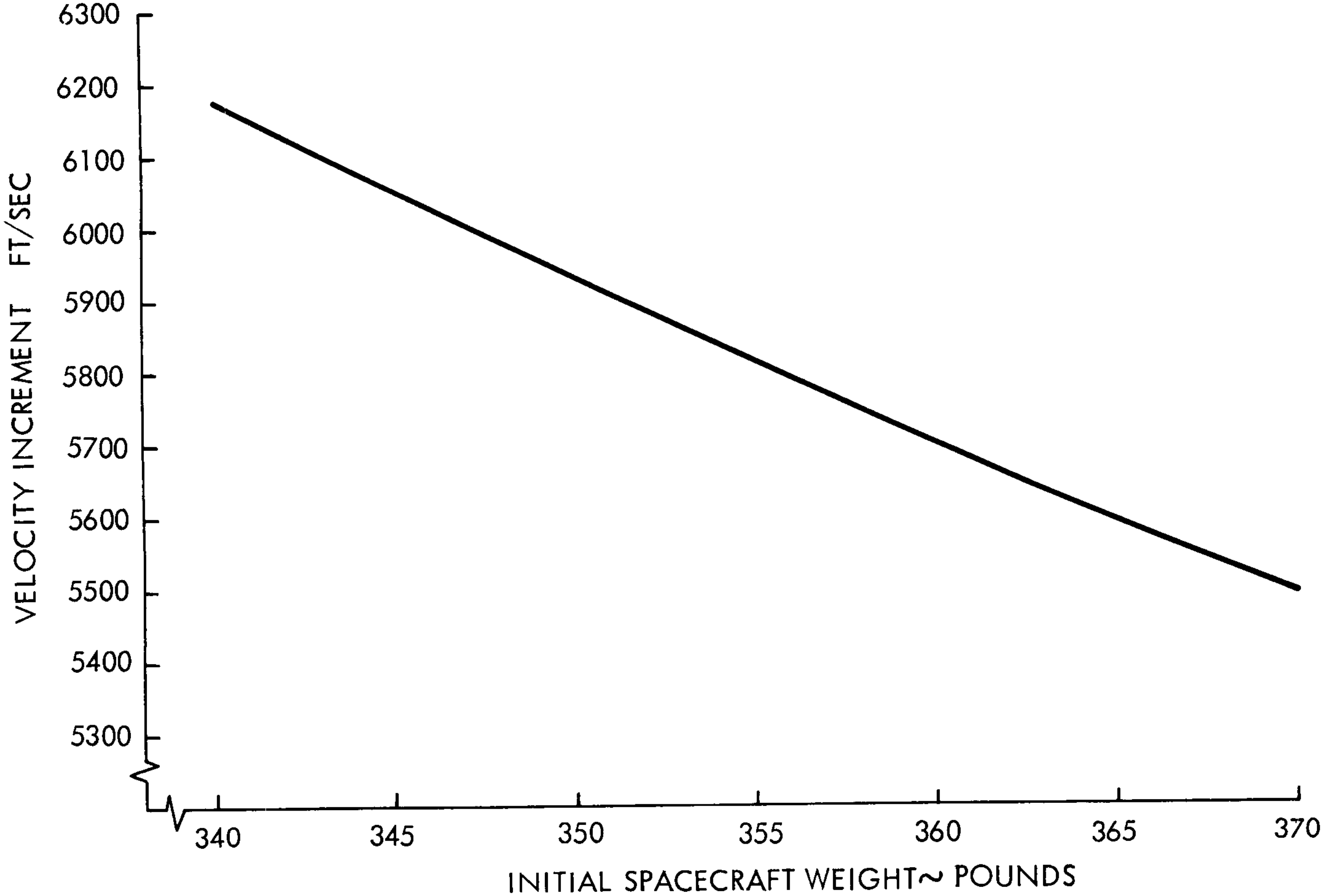


FIGURE 28
VELOCITY INCREMENT CAPABILITY
OF THE PATHFINDER MOTOR